HETEROGENEOUS SHALLOW-SHELF CARBONATE BUILDUPS IN THE PARADOX BASIN, UTAH AND COLORADO: TARGETS FOR INCREASED OIL PRODUCTION AND RESERVES USING HORIZONTAL DRILLING TECHNIQUES

SEMI-ANNUAL TECHNICAL PROGRESS REPORT April 6 - October 5, 2001

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Thomas C. Chidsey, Jr., Principal Investigator/Program Manager,
Utah Geological Survey
David E. Eby, Eby Petrography & Consulting, Inc.
and
Laura L. Wray, Colorado Geological Survey

October 2001

Contract No. DE-FC26-00BC15128

Gary D. Walker, Contract Manager
U.S. Department of Energy
National Petroleum Technology Office
P.O. Box 3628
Tulsa, OK 74101-3628

DISCLAIMER

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ABSTRACT

The Paradox Basin of Utah, Colorado, Arizona, and New Mexico contains nearly 100 small oil fields producing from carbonate buildups within the Pennsylvanian (Desmoinesian) Paradox Formation. These fields typically have one to 10 wells with primary production ranging from 300,000 to 2,000,000 barrels (48,000-318,000 m^3) of oil per field and a 15 to 20 percent recovery rate. At least 200 million barrels (31.8 million m^3) of oil will not be recovered from these small fields because of inefficient recovery practices and undrained heterogeneous reservoirs. Several fields in southeastern Utah and southwestern Colorado are being evaluated for horizontal drilling from existing vertical field wells based upon geological characterization and reservoir modeling case studies. The results of these studies can be applied to similar fields in the Paradox Basin and the Rocky Mountain region, the Michigan and Illinois Basins, and the Midcontinent region.

This report covers research activities for the first half of the second project year (April 6, through October 5, 2001). This work includes description and analysis of cores from regional exploratory wells, reservoir mapping, and technology transfer activities. Geological characterization of regional facies belts is focusing on reservoir heterogeneity and lateral continuity to determine major facies types, and grade various intervals for horizontal drilling suitability. Depositional facies include: basinal, open-marine shelf, open-marine organic buildups, calcarenites at the platform edge, middle shelf or open platform interior, restricted inner shelf or platform interior evaporites, and shoreline and terrestrial siliciclastic deposits. Lithofacies from the middle shelf or open platform interior, principally the phylloid-algal mounds, form the dominant producing reservoirs in the Ismay and Desert Creek zones.

Geological characterization on a local scale focused on reservoir heterogeneity, quality, and lateral continuity, as well as possible compartmentalization, within Cherokee field, Utah. This study utilizes representative core and geophysical logs to characterize and grade the field's potential for drilling horizontal laterals from existing development wells. Utilizing a log-based correlation scheme, structure contour and isochore maps from units in the upper Ismay zone for Cherokee field show carbonate buildup trends, define limits of field potential, and also indicate possible horizontal drilling targets. From these evaluations, untested or under-produced compartments will be identified as targets for horizontal drilling.

Technology transfer activities consisted of exhibiting a booth display of project materials at the annual national convention of the American Association of Petroleum Geologists, a technical presentation, publications, and newsletters. Project team members met with the Technical Advisory and Stake Holders Boards to review the project activities and results. The project home page was updated for the Utah Geological Survey and Colorado Geological Survey Internet web sites.

EXECUTIVE SUMMARY

The project's primary objective is to enhance domestic petroleum production by demonstration and transfer of horizontal drilling technology in the Paradox Basin, Utah, Colorado, Arizona, and New Mexico. If this project can demonstrate technical and economic feasibility, then the technique can be applied to approximately 100 additional small fields in the Paradox Basin alone, and result in increased recovery of 25 to 50 million barrels (4-8 million m^3) of oil. This project is designed to characterize several shallow-shelf carbonate reservoirs in the Pennsylvanian (Desmoinesian) Paradox Formation, choose the best candidate(s) for a pilot demonstration project to drill horizontally from existing vertical wells, monitor well performance(s), and report associated validation activities.

The Utah Geological Survey heads a multidisciplinary team to determine the geological and reservoir characteristics of typical, small, shallow-shelf, carbonate reservoirs in the Paradox Basin. The Paradox Basin technical team consists of the Utah Geological Survey (prime contractor), Colorado Geological Survey, Eby Petrography & Consulting Inc., and Seeley Oil Company. This research is funded by the Class II Oil Revisit Program of the U.S. Department of Energy, National Petroleum Technology Office (NPTO) in Tulsa, Oklahoma. This report covers research activities for the first half of the second project year (April 6 through October 5, 2001). This work includes: description and analysis of cores from regional exploratory wells; reservoir mapping in Cherokee field, San Juan County, Utah; and technology transfer activities. From these evaluations, untested or under-produced reservoir compartments can be identified as targets for horizontal drilling. The results can be applied to similar reservoirs in many U.S. basins.

The two main producing zones of the Paradox Formation are the Ismay and the Desert Creek. Establishment of the basic carbonate lithofacies belts and stratigraphic patterns within the Ismay and Desert Creek zones in the Blanding sub-basin are critical to the understanding of the fields being evaluated for the demonstration project. Geological characterization of facies on a regional scale is focusing on reservoir heterogeneity and lateral continuity. Reservoir data, cores and cuttings, geophysical logs, various reservoir maps, and other information from regional exploratory wells are being collected. Well locations, production reports, completion tests, core analysis, formation tops, and other data are being compiled and entered in a database developed by the Utah Geological Survey, from which core descriptions are graphically produced. This task is ultimately designed to map regional lithofacies belts, determine major facies types, and grade various intervals for horizontal drilling suitability.

The Ismay zone is dominantly limestone comprising equant buildups of phylloid-algal material. The Desert Creek zone is dominantly dolomite comprising regional nearshore shoreline trends with highly aligned, linear facies tracts. The depositional environments of the Ismay and Desert Creek zones, based on the core descriptions, show that the controlling factors were water depth, salinity, prevailing wave energy, and in the case of phylloid-algal growth, paleostructural position. Depositional facies include: basinal, open-marine shelf, open-marine organic buildups, calcarenites at the platform edge (including carbonate islands), middle shelf or open platform interior, restricted inner shelf or platform interior evaporites, and shoreline and terrestrial siliciclastic deposits. Lithofacies from the middle shelf or open platform interior, principally the phylloid-algal mounds, form the dominant producing reservoirs in the Ismay and Desert Creek zones.

The log-based correlation scheme developed for the project ties the typical, vertical, core-derived sequence or cycle of depositional facies from the Cherokee case-study field, San Juan County, Utah, to its corresponding sequence of gamma-ray and neutron-density curves from geophysical well logs. The correlation scheme identifies major zone contacts, seals or barriers, baffles, producing or potential reservoirs, and depositional facies. In Cherokee field, six porosity units were identified in the upper Ismay zone. However, geophysical logs often exhibit a "false porosity" for some units that led to wasteful completion attempts. The cores reveal these zones actually represent barriers or baffles to fluid flow. Log-defined units with real porosity represent potential targets for horizontal drilling and warrant further investigation. Structure contour and isochore maps from units in the upper Ismay zone for Cherokee field, show carbonate buildup trends, define limits of field potential, and also indicate possible horizontal drilling targets.

Technology transfer activities consisted of exhibiting a booth display of project materials at the 2001 annual national convention of the American Association of Petroleum Geologists in Denver, Colorado. A poster and core technical presentation was also made at the convention. Technical team members met with the Technical Advisory and Stake Holders Boards to review project activities and results. The project home page was updated for the Utah Geological Survey and Colorado Geological Survey Internet web sites. The project team members submitted an abstract to the American Association of Petroleum Geologists for a presentation during the 2002 annual convention in Houston, Texas. Newsletters were published with an overview of the project. Project team members published an abstract, semi-annual reports, and newsletters detailing project progress and results.

INTRODUCTION

Geologic Setting

The Paradox Basin is located mainly in southeastern Utah and southwestern Colorado, with a small portion in northeastern Arizona and northwestern New Mexico (figure 1). The Paradox Basin is an elongate, northwest-southeast-trending evaporitic basin that predominately developed during the Pennsylvanian (Desmoinesian), about 330 to 310 million years ago (Ma). During the Pennsylvanian, a pattern of basins and fault-bounded uplifts developed from Utah to Oklahoma as a result of the collision of South America, Africa, and southeastern North America (Kluth and Coney, 1981; Kluth, 1986), or from a smaller scale collision of a microcontinent with south-central North America (Harry and Mickus, 1998). One result of this tectonic event was the uplift of the Ancestral Rockies in the western United States. The Uncompahgre Highlands in eastern Utah and western Colorado initially formed as the westernmost range of the Ancestral Rockies during this ancient mountain-building period. The

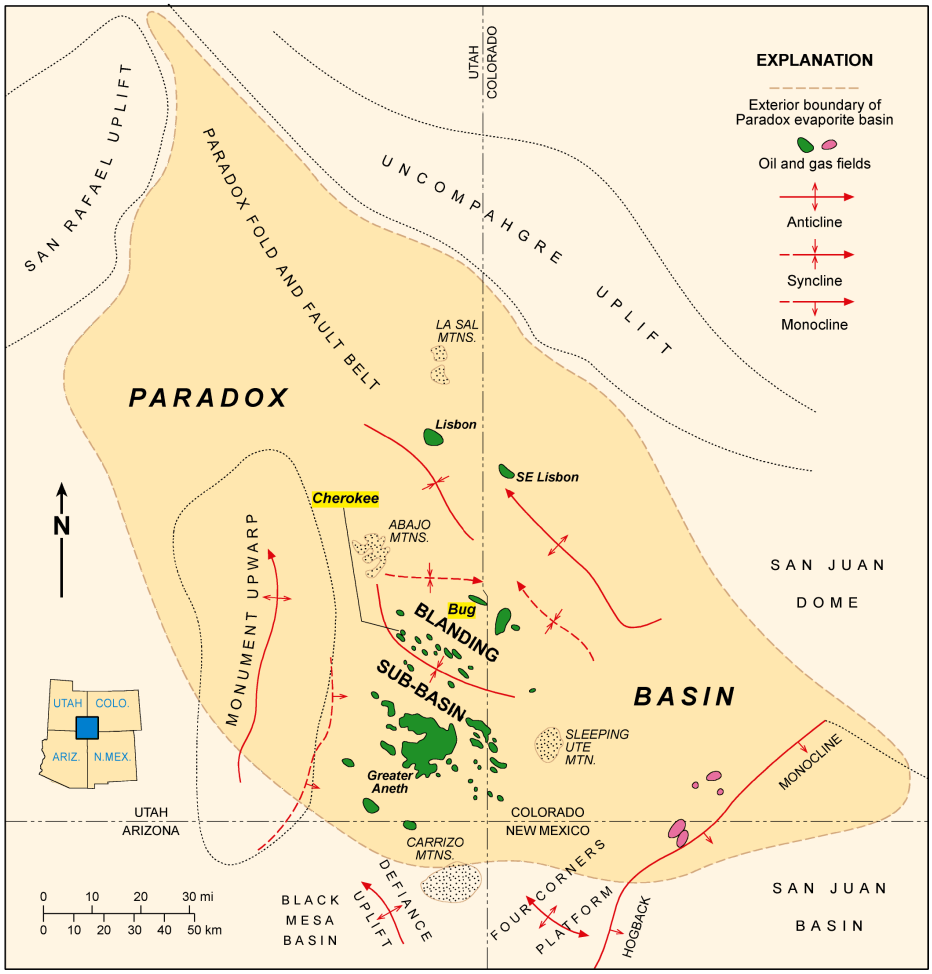


Figure 1. Location map of the Paradox Basin, Utah, Colorado, Arizona, and New Mexico showing producing oil and gas fields, the Paradox fold and fault belt, and Blanding sub-basin as well as surrounding Laramide basins and uplifts (modified from Harr, 1996).

southwestern flank of the Uncompahgre Highlands (uplift) is bounded by a large basement-involved, high-angle reverse fault identified from seismic surveys and exploration drilling. As the highlands rose, an accompanying depression, or foreland basin, formed to the southwest – the Paradox Basin. Rapid subsidence, particularly during the Pennsylvanian and continuing into the Permian, accommodated large volumes of evaporitic and marine sediments that intertongue with non-marine arkosic material shed from the highland area to the northeast (Hintze, 1993). The Paradox Basin is surrounded by other uplifts and basins, which formed during the Late Cretaceous-early Tertiary Laramide orogeny (figure 1).

The Paradox Basin can generally be divided into two areas: the Paradox fold and fault belt in the north, and the Blanding sub-basin in the south-southwest (figure 1). Most oil production comes from the Blanding sub-basin. The source of the oil is several black, organic-rich shales within the Paradox Formation (Hite and others, 1984; Nuccio and Condon, 1996). The relatively undeformed Blanding sub-basin developed on a shallow-marine shelf that locally contained algal-mound and other carbonate buildups in a subtropical climate.

The two main oil-producing zones of the Paradox Formation are informally named the Ismay and the Desert Creek (figure 2). The Ismay zone is dominantly limestone comprising equant buildups of phylloid-algal material with locally variable small-scale subfacies (figure 3A) and capped by anhydrite. The Ismay produces oil from fields in the southern Blanding sub-basin (figure 4). The Desert Creek zone is dominantly dolomite comprising regional nearshore shoreline trends with highly aligned, linear facies tracts (figure 3B). The Desert Creek produces oil in fields in the central Blanding sub-basin (figure 4). Both the Ismay and Desert Creek buildups generally trend northwest-southeast. Various facies changes and extensive diagenesis have created complex reservoir heterogeneity within these two diverse zones.

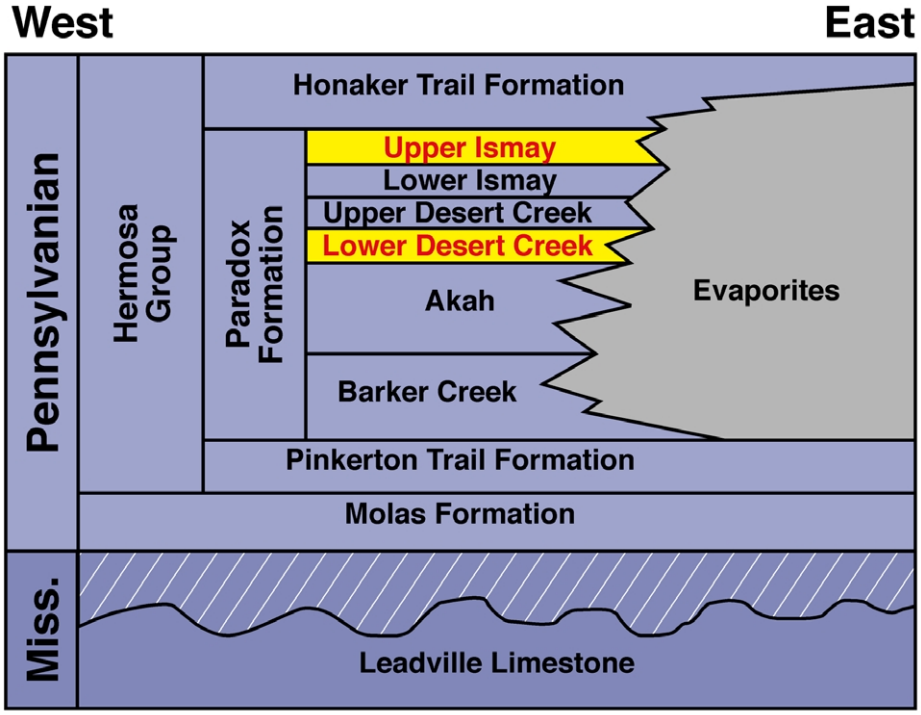


Figure 2. Pennsylvanian stratigraphy of the southern Paradox Basin including informal zones of the Paradox Formation.

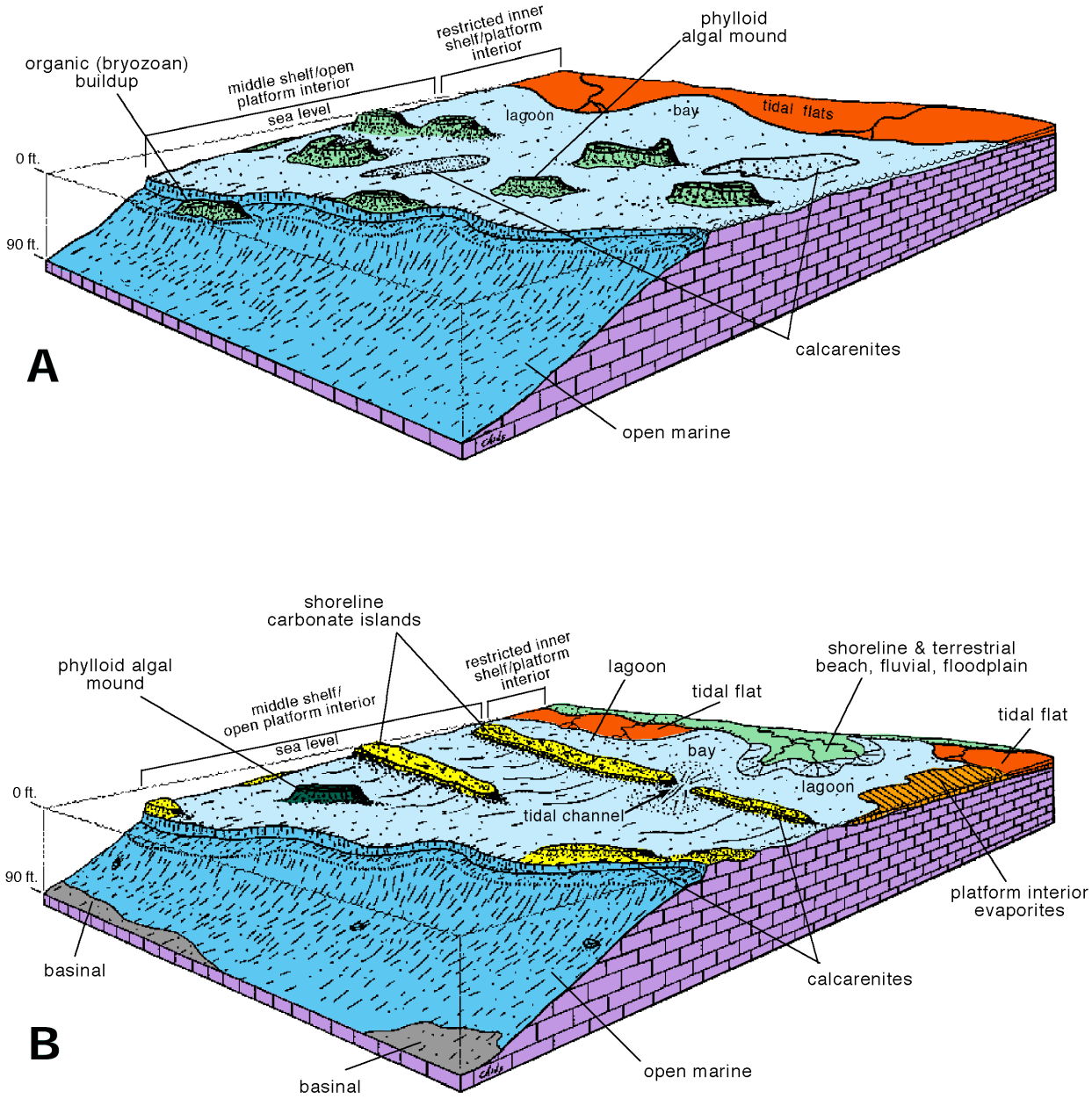


Figure 3. Block diagrams displaying major depositional facies, as determined from core, for the Ismay (A) and Desert Creek (B) zones, Pennsylvanian Paradox Formation, Utah and Colorado.

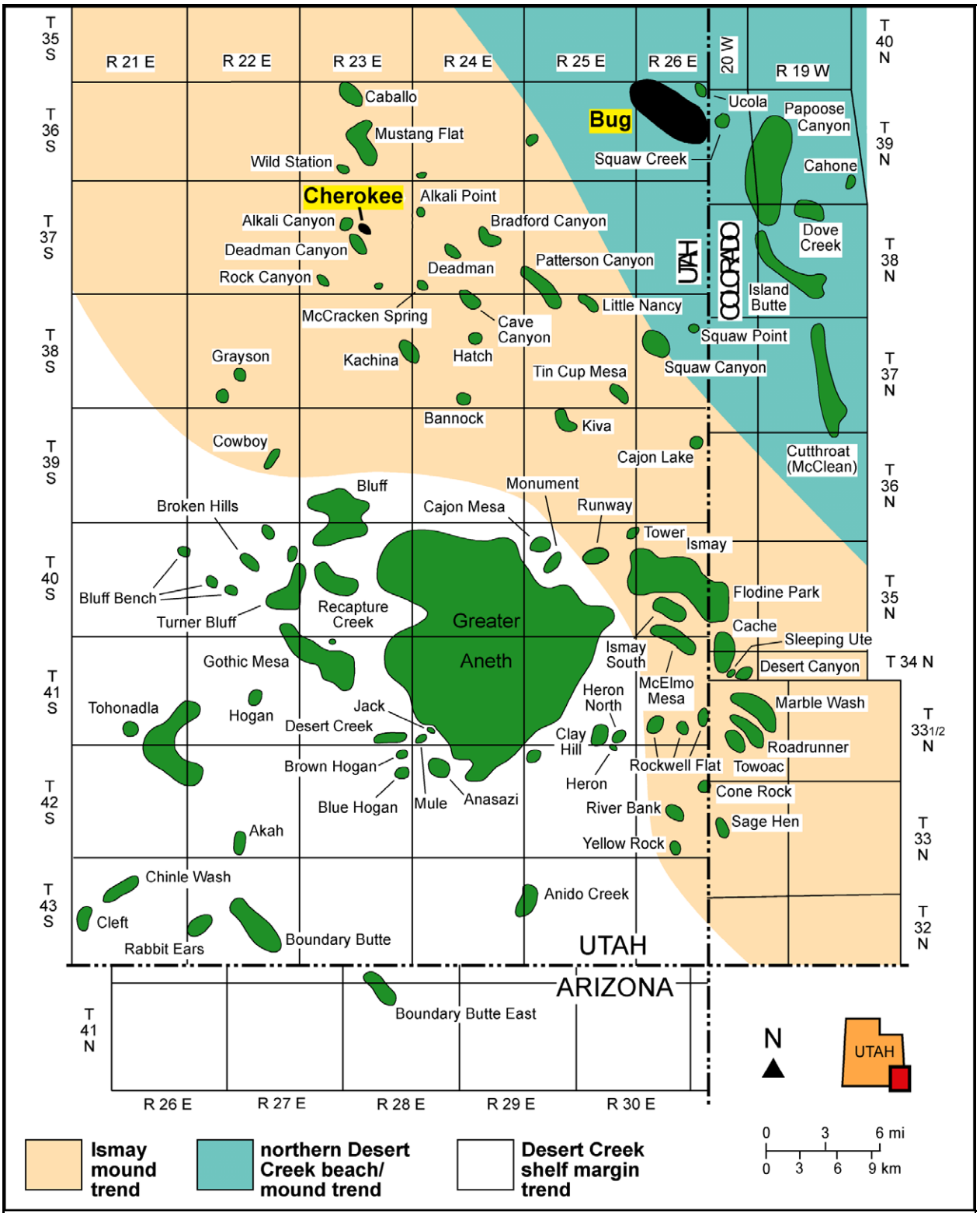


Figure 4. Map showing the project study area and fields within the Ismay and Desert Creek producing trends in the Blanding sub-basin, Utah and Colorado.

Project Overview

Over 400 million barrels (64 million m^3) of oil have been produced from the shallow-shelf carbonate reservoirs in the Pennsylvanian Paradox Formation in the Paradox Basin. With the exception of the giant Greater Aneth field, the other 100-plus oil fields in the basin typically contain 2 to 10 million barrels (0.3-1.6 million m^3) of original oil in place. Most of these fields are characterized by high initial production rates followed by a very short productive life (primary), and hence premature abandonment. Only 15 to 25 percent of the original oil in place is recoverable during primary production from conventional vertical wells.

An extensive and successful horizontal drilling program has been conducted in the giant Greater Aneth field. However, to date, only two horizontal wells have been drilled in small Ismay and Desert Creek fields. The results from these wells were disappointing due to poor understanding of the carbonate facies and diagenetic fabrics that create reservoir heterogeneity. These small fields, and similar fields in the basin, are at high risk of premature abandonment. At least 200 million barrels (31.8 million m^3) of oil will be left behind in these small fields because current development practices leave compartments of the heterogeneous reservoirs undrained. Through proper geological evaluation of the reservoirs, production may be increased by 20 to 50 percent through the drilling of low-cost single or multilateral horizontal legs (figure 5) from existing vertical development wells. In addition, horizontal drilling from existing wells minimizes surface disturbances and costs for field development, particularly in the environmentally sensitive areas of southeastern Utah and southwestern Colorado.

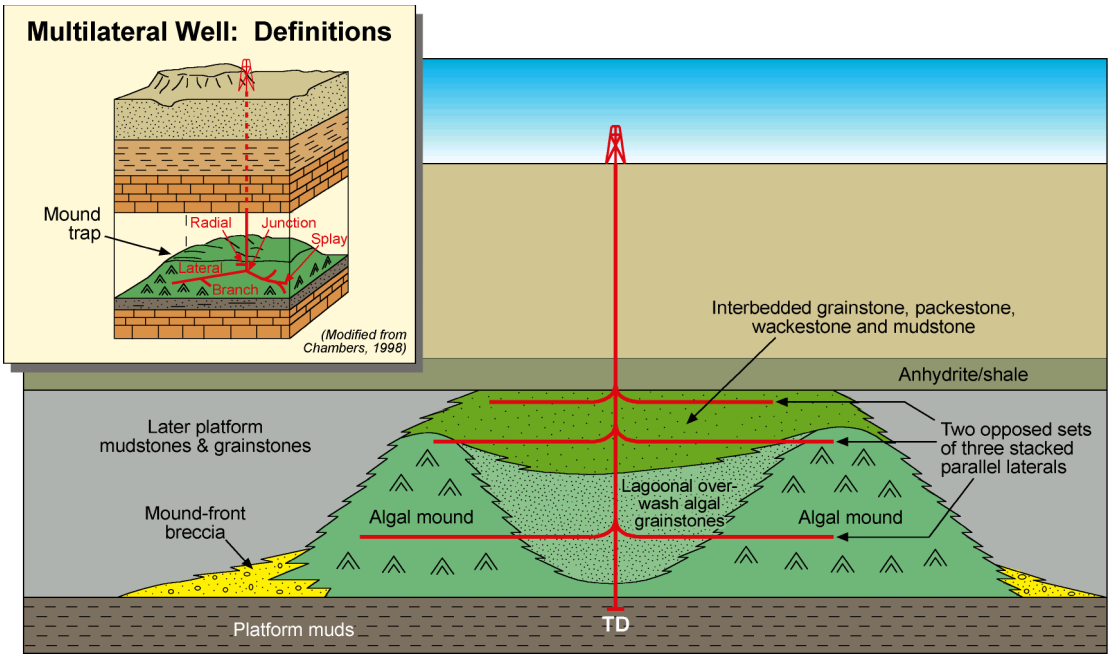


Figure 5. Schematic diagram of Ismay zone drilling targets by multilateral (horizontal) legs from an existing field well.

The Utah Geological Survey (UGS), Colorado Geological Survey (CGS), Eby Petrography & Consulting, Inc., and Seeley Oil Company have entered into a cooperative agreement with the U.S. Department of Energy (DOE) as part of its Class II Oil Revisit Program. A three-phase, multidisciplinary approach will be used to increase production and reserves from the shallow-shelf carbonate reservoirs in the Ismay and Desert Creek zones of the Paradox Basin. Phase 1 is the geological and reservoir characterization of selected, diversified small fields, including Cherokee and Bug fields in San Juan County, Utah (figure 4), to identify the field(s) having the greatest potential as targets for increased well productivity and ultimate recovery in a pilot demonstration project. This phase will include: (a) determination of regional geological setting; (b) analysis of the reservoir heterogeneity, quality, lateral continuity, and compartmentalization within the field; (c) construction of lithologic, microfacies, porosity, permeability, and net pay maps of the field; (d) determination of field reserves and recovery; and (e) integration of geological data in the design of single or multiple horizontal laterals from existing vertical wells.

Phase 2 is a field demonstration project of the horizontal drilling techniques identified as having the greatest potential for increased field productivity and ultimate recovery. The demonstration project will involve drilling one or more horizontal laterals from the existing vertical field well(s) to maximize production from the zones of greatest potential.

Phase 3 includes: (a) reservoir management and production monitoring, (b) economic evaluation of the results, and (c) determination of the ability to transfer project technologies to other similar fields in the Paradox Basin and throughout the U.S.

Phases 1, 2, and 3 will have continuous, but separate, technical transfer activities including: (a) an industry outreach program and project newsletters; (b) a core workshop/short coarse in Salt Lake City; (c) publications and technical presentations; (d) a project home page on the Utah Geological Survey and Colorado Geological Survey Internet web sites; (e) digital databases, maps, and reports; (f) a summary of regulatory, economic, and financial needs; and (g) annual meetings with a Technical Advisory Board and Stake Holders Board.

Project Benefits and Potential Application

The overall benefit of this multi-year project would be enhanced domestic petroleum production by demonstrating and transferring an advanced-oil-recovery technology throughout the small oil fields of the Paradox Basin. Specifically, the benefits expected from the project are: (1) increasing recovery and reserve base by identifying untapped compartments created by reservoir heterogeneity; (2) preventing premature abandonment of numerous small fields; (3) increasing deliverability by horizontally drilling along the reservoir's optimal fluid-flow paths; (4) identifying reservoir trends for field extension drilling and stimulating exploration in Paradox Basin fairways; (5) reducing development costs by more closely delineating minimum field size and other parameters necessary for horizontal drilling; (6) allowing for minimal surface disturbance by drilling from existing vertical field wells; (7) allowing limited energy investment dollars to be used more productively; and (8) increasing royalty income to the Federal, state, and local governments, the Ute Mountain Ute Indian Tribe, and fee owners. These benefits may also apply to other areas including: algal-mound and carbonate buildup reservoirs on the eastern and northwest shelves of the Permian Basin in Texas, Silurian pinnacle and patch reefs of the Michigan and Illinois Basins, and shoaling carbonate island trends of the Williston Basin.

The results of this project are transferred to industry and other researchers through establishment of Technical Advisory and Stake Holders Boards, an industry outreach program, digital project databases, and web pages. Project results will be disseminated via technical workshops and seminars, field trips, technical presentations at national and regional professional meetings, and papers in newsletters and various technical or trade journals.

REGIONAL FACIES

Establishment of the basic carbonate lithofacies belts and stratigraphic patterns within shallow-shelf carbonate Ismay and Desert Creek zones of the Paradox Formation in the Blanding sub-basin are critical to the understanding of the fields being evaluated for the demonstration project. Geological characterization of facies on a regional scale is focussing on reservoir heterogeneity and lateral continuity. This task is utilizing representative core and modern geophysical well logs to characterize and initially grade various intervals in the region for horizontal drilling suitability.

Data Collection and Compilation

Reservoir data, cores and cuttings, geophysical logs, various reservoir maps, and other information from regional exploratory wells are being collected by the UGS and CGS. Well locations, production data, completion tests, basic core analysis, formation tops, porosity and permeability data, and other data are being compiled and entered in a database developed by the UGS. This database, INTEGRAL, is a geologic-information database that links a diverse set of geologic data to records using MS Access™. The database is designed so that geological information, such as lithology, petrophysical analyses, or depositional environment, can be exported to software programs to produce strip logs, lithofacies maps, various graphs, statistical models, and other types of presentations. The database containing information on the geological and reservoir characterization study will be available at the UGS's and CGS's Paradox Basin project Internet web sites at the conclusion of the project.

Conventional cores from 24 exploratory wells in the Blanding-sub-basin were described (figure 6). Special emphasis is being placed on identifying the flow unit's bounding surfaces and depositional environments. The core descriptions follow the guidelines of Bebout and Loucks (1984) which include: (1) basic porosity types, (2) mineral composition in percentage, (3) nature of contacts, (4) carbonate structures, (5) carbonate textures in percentage, (6) carbonate fabrics, (7) color, and (8) fossils (figure 7). Carbonate fabrics were determined according to Dunham's (1962) and Embry and Klovan's (1971) classification schemes.

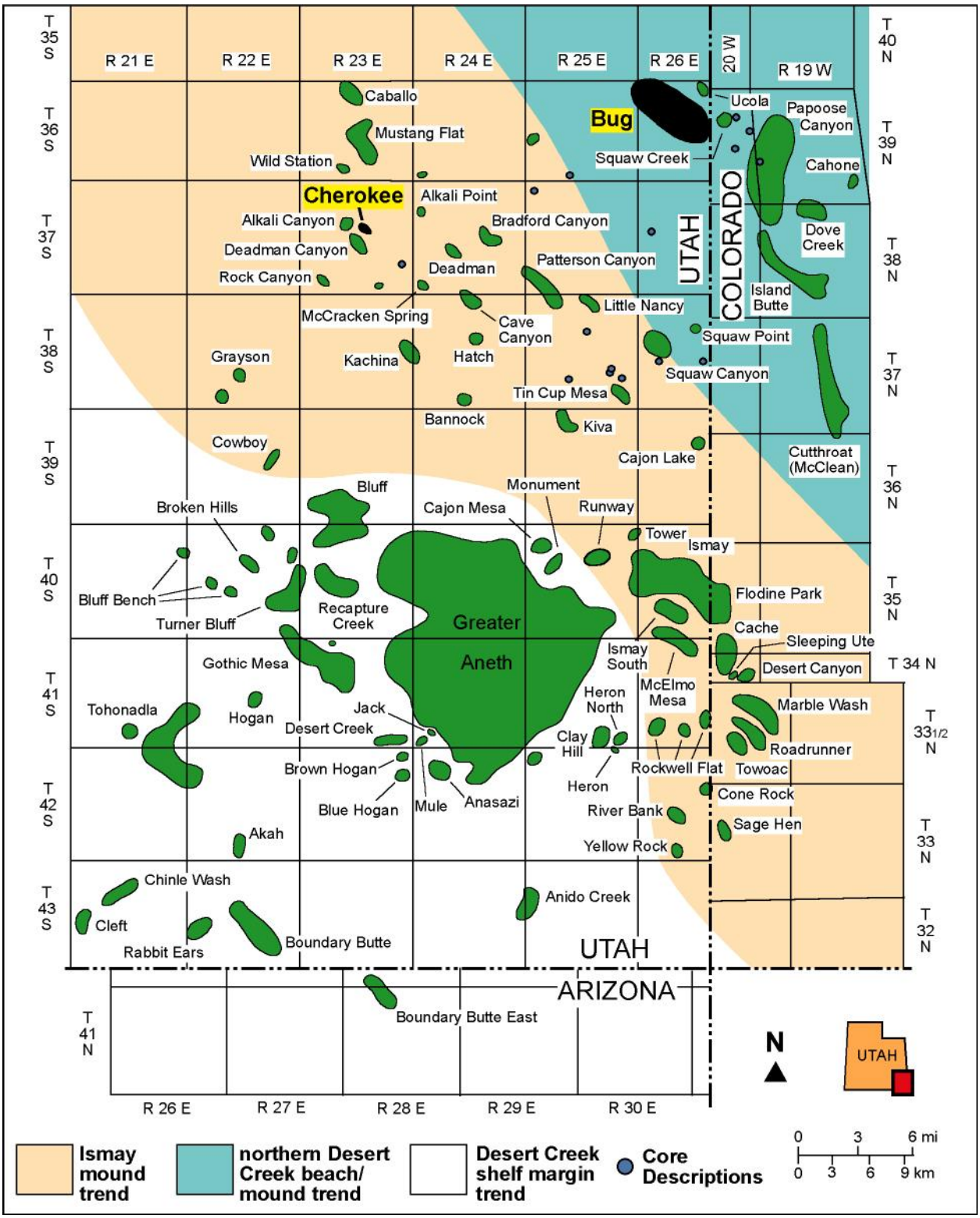


Figure 6. Map showing location of regional exploratory wells, within the Ismay and Desert Creek producing trends in the Blanding sub-basin, with cores described during the project period.

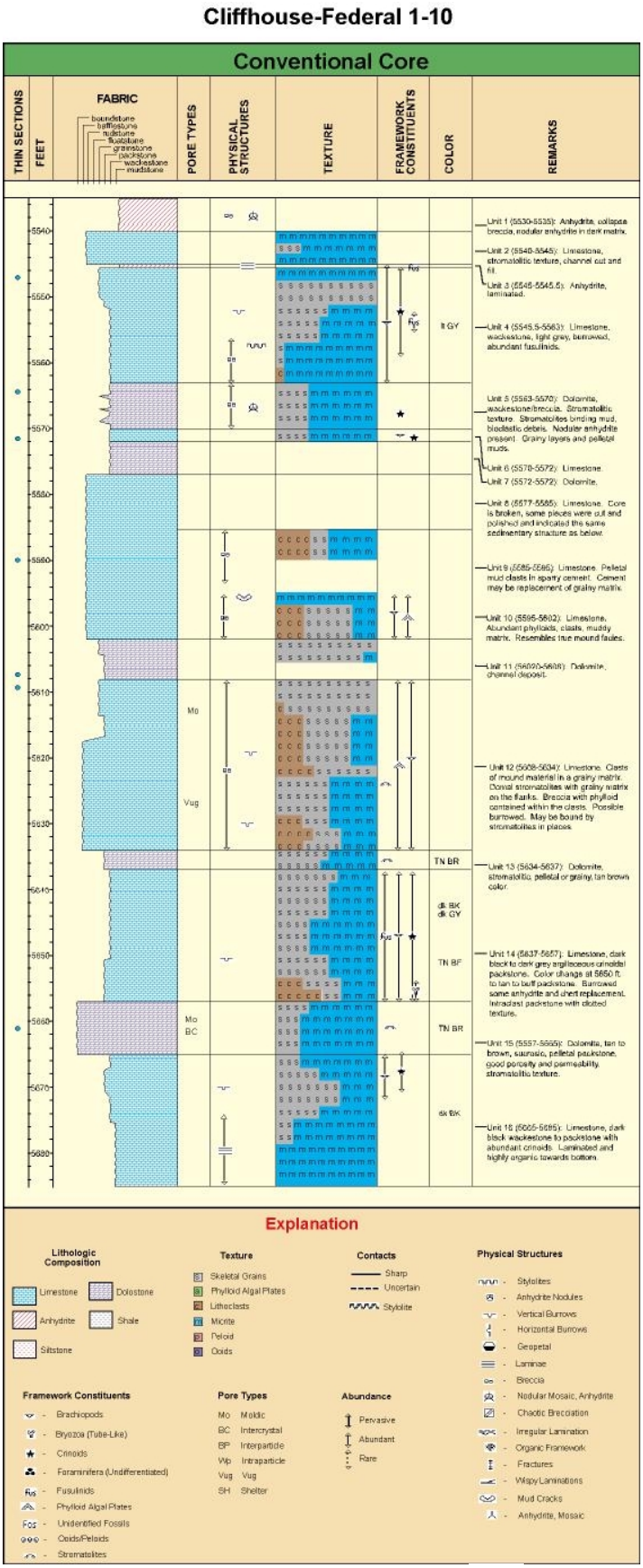


Figure 7. Typical core description of the Ismay zone, Cliffhouse-Federal 1-10 exploratory well, section 11, T. 38 S., R. 25 E., Salt Lake Base Line and Meridian, San Juan County, Utah.

Depositional Environments

A preliminary determination of the Ismay and Desert Creek depositional environments was made based on the core descriptions. These are shown schematically on figure 3. The controls on the development of each depositional environment (lithofacies) were water depth, salinity, prevailing wave energy, and paleostructural position. In the Ismay zone, the following depositional facies are recognized thus far from cores: open-marine shelf, organic buildups and calcarenites at the platform edge; middle shelf or open platform interior; and restricted inner shelf or platform interior. In the Desert Creek zone, the following depositional facies are recognized thus far from cores: basinal, calcarenites (carbonate islands) at the platform edge; middle shelf or open platform interior; restricted inner shelf or platform interior; platform interior evaporites; and shoreline and terrestrial siliciclastic deposits.

The basinal environment represents deep water (90 to 120 feet [27-37 m]) and euxinic conditions. Lithofacies from Desert Creek zone cores include: (1) black to dark gray, non-calcareous, non-fossiliferous shale and silty shale; (2) spiculitic limestone; (3) pelagic lime mudstone with microfossils and occasional thin-shelled bivalves such as *Halobia*; and (4) thick, deep water siliciclastic sands. The open-marine lithofacies in the Ismay zone core were deposited below wave base and consist of wackestone, argillaceous limestone, and fossilferous shales containing crinoids, brachiopods, and byrozoans. The organic buildups at the platform edge from Ismay core are represented by byrozoan-bearing packstones and wackestones.

Calcarenites are recognized in both zones and represent moderate- to high-energy, regularly agitated, marine environments where shoals and/or islands developed. Sediment deposition and modification probably occurred from 5 feet (1.5 m) above sea level to 45 feet (14 m) below sea level. These platform edge deposits include: (1) oolitic and coated grain sands; (2) crinoid, foram, algal, and fusilinid sands; (3) small, benthic foram and hard peloid sands representing stabilized peloid grain flats; and (4) shoreline carbonate islands of shell hash.

The middle shelf or open platform interior represents a well-circulated, low- to moderate-energy, normal salinity, shallow-water (between 0 and 90 feet [0-27 m]) environment. Lithofacies from this environment form the dominant producing reservoirs in the Ismay and Desert Creek zones. Benthic forams, bivalve molluscs, and phylloid algae (*Ivanovia*) are common. Echinoderms are rare and open-marine cephalopods are generally absent. Lithofacies include: (1) limey peloidal sands and muds frequently with burrow traces; (2) fossiliferous peloidal wackstone; and (3) phylloid-algal mounds. The principal buildup process, phylloid-algal growth, occurred during high stands of sea level. Paleotopography from Mississippian-aged normal faulting produced the best marine conditions for initial algal growth.

The restricted inner shelf or platform interior represents shallow water (0 to 45 feet [0-14 m]), and generally low energy and poor circulation conditions. Fauna are limited mainly to stromatolitic algae, gastropods, certain benthic forams, and ostracods. Lithofacies include: (1) bioclastic lagoonal to bay wackestone; (2) tidal flat muds often with early dolomite; and (3) shoreline carbonate islands with birdseye fenestrae, stromatolites, cryptoalgal laminations, and dolomitic crusts. Platform interior evaporites, usually anhydrite, were deposited in salinity restricted areas.

Shoreline and terrestrial siliciclastic deposits represent beach, fluvial, and flood-plain environments. These siliciclastic deposits include argillaceous to dolomitic siltstone with rip-up clasts, scour surfaces, or mudcracks.

GEOLOGICAL CHARACTERIZATION OF CHEROKEE FIELD, SAN JUAN COUNTY, UTAH – RESULTS AND DISCUSSION

Two Utah fields were selected for local-scale evaluation during Budget Period I of the project: Cherokee in the Ismay trend and Bug in the Desert Creek trend (figure 4). Others may be evaluated later. This evaluation has included data collection, core photography and description, determination of a typical vertical sequence from conventional core tied to its corresponding log response, determination of diagenetic fabrics from thin sections, and plots of core plug porosity versus permeability of these fields. This geological characterization focused on reservoir heterogeneity, quality, and lateral continuity, as well as possible compartmentalization within the fields. From these evaluations, untested or under-produced compartments can be identified as targets for horizontal drilling. The models resulting from the geological and reservoir characterization of these fields can be applied to similar fields in the basin (and other basins as well) where data might be limited.

During this project period, work on centered reservoir mapping in Cherokee field using a log-based correlation scheme.

Field Overview

Cherokee field (figure 4) is a phylloid-algal buildup capped by anhydrite that produces oil from porous algal limestone and dolomite in the upper Ismay zone. The net reservoir thickness is 27 feet (8.2 m), which extends over a 320-acre (130 ha) area. Porosity averages 12 percent with 8 millidarcies (md) of permeability in vuggy and intercrystalline pore systems. Water saturation is 38.1 percent (Crawley-Stewart and Riley, 1993).

Cherokee field was discovered in 1987 with the completion of the Meridian Oil Company Cherokee Federal 11-14, NE1/4NW1/4 section 14, T. 37 S., R. 23 E., Salt Lake Base Line and Meridian (SLBL&M); initial flowing potential was 53 barrels of oil per day (BOPD) (8.4 m^3), 990 thousand cubic feet of gas per day (MCFGPD) (28 MCMPD), and 26 barrels of water (4.1 m^3). There are currently four producing (or shut-in) wells and two dry holes in the field. The well spacing is 80 acres (32 ha). The present field reservoir pressure is estimated at 150 pounds per square inch (psi) (1,034 kpa). Cumulative production as of June 1, 2001 (the latest available information), was 180,845 barrels of oil (28,754 m^3), 3.61 billion cubic feet of gas (BCFG) (0.1 BCMG), and 2,758 barrels of water (439 m^3) (Utah Division of Oil, Gas and Mining, 2001). The original, estimated, primary recovery is 172,000 barrels of oil (27,348 m^3) and 3.28 BCFG (0.09 BCMG) (Crawley-Stewart and Riley, 1993). The fact that both these estimates have been surpassed suggests significant additional reserves could remain.

Log-Based Correlation Scheme

The typical, vertical, core-derived sequence or cycle of depositional facies from Cherokee field was tied to its corresponding sequence of gamma-ray and neutron-density curves from geophysical well logs. The correlation scheme identifies major zone contacts, seals or barriers, baffles, producing or potential reservoirs, and depositional facies (figure 8 and table 1). These contacts will be used to produce a variety of structure and isochore maps that will be incorporated into the reservoir models.

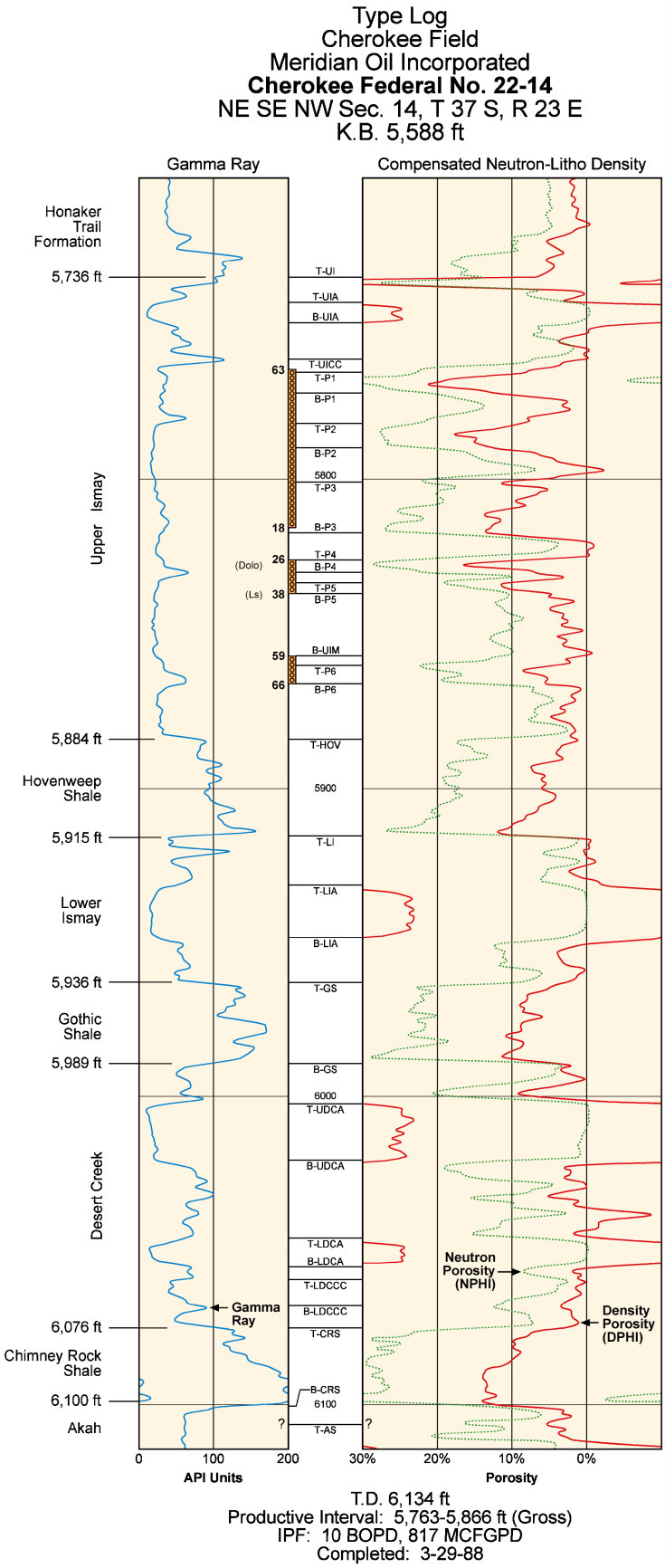


Figure 8. Type log for the Cherokee field (gamma-ray, compensated neutron-litho density) from the Cherokee Federal No. 22-14 well, showing the Ismay and Desert Creek correlation scheme, major units, and productive intervals (refer to table 1 for explanation of unit abbreviations).

Table 1. Correlation scheme used for Ismay and Desert Creek zones of the Paradox Formation in Cherokee field, Blanding sub-basin, Utah.

Unit Code	Description
T-UI	Top - Upper Ismay Zone
T-UIA	Top - Upper Ismay Anhydrite
B-UIA	Base - Upper Ismay Anhydrite
T-UICC	Top - Upper Ismay Clean Carbonate
T-P1	Top - Porosity Unit #1
B-P1	Base - Porosity Unit #1
T-P2	Top - Porosity Unit #2
B-P2	Base - Porosity Unit #2
T-P3	Top - Porosity Unit #3
B-P3	Base - Porosity Unit #3
T-P4	Top - Porosity Unit #4
B-P4	Base - Porosity Unit #4
T-P5	Top - Porosity Unit #5
B-P5	Base - Porosity Unit #5
B-UIM	Base - Upper Ismay Mound
B-UICC	Base Upper Ismay Clean Carbonate
T-P6	Top - Porosity Unit #6
B-P6	Base - Porosity Unit #6
T-HOV	Top – Hovenweep Shale
T-LI	Top - Lower Ismay Zone
T-LIA	Top - Lower Ismay Anhydrite
B-LIA	Base - Lower Ismay Anhydrite
T-GS	Top - Gothic Shale
B-GS	Base - Gothic Shale
T-UDCA	Top - Upper Desert Creek Anhydrite
B-UDCA	Base - Upper Desert Creek Anhydrite
T-LDCA	Top - Lower Desert Creek Anhydrite
B-LDCA	Base - Lower Desert Creek Anhydrite
T-LDCMC	Top - Lower Desert Creek Mound Cap
B-LDCM	Base - Lower Desert Creek Mound
T-LDCCC	Top - Lower Desert Creek Clean Carbonate
B-LDCCC	Base - Lower Desert Creek Clean Carbonate
T-CRS	Top - Chimney Rock Shale
B-CRS	Base - Chimney Rock Shale
T-AS	Top - Akah Subaerial

Seals or barriers include anhydite layers and thick (black) shales such as the Hovenweep shale, which separates the upper Ismay from the lower Ismay. Baffles are those rock units that restrict fluid flow in some parts of the field, but may develop enough porosity and permeability in other parts, through diagenetic processes or facies changes, to provide a conduit for fluid flow or even oil storage. The reservoirs are those units containing 6 percent or more porosity based on the average of the neutron and density porosity values.

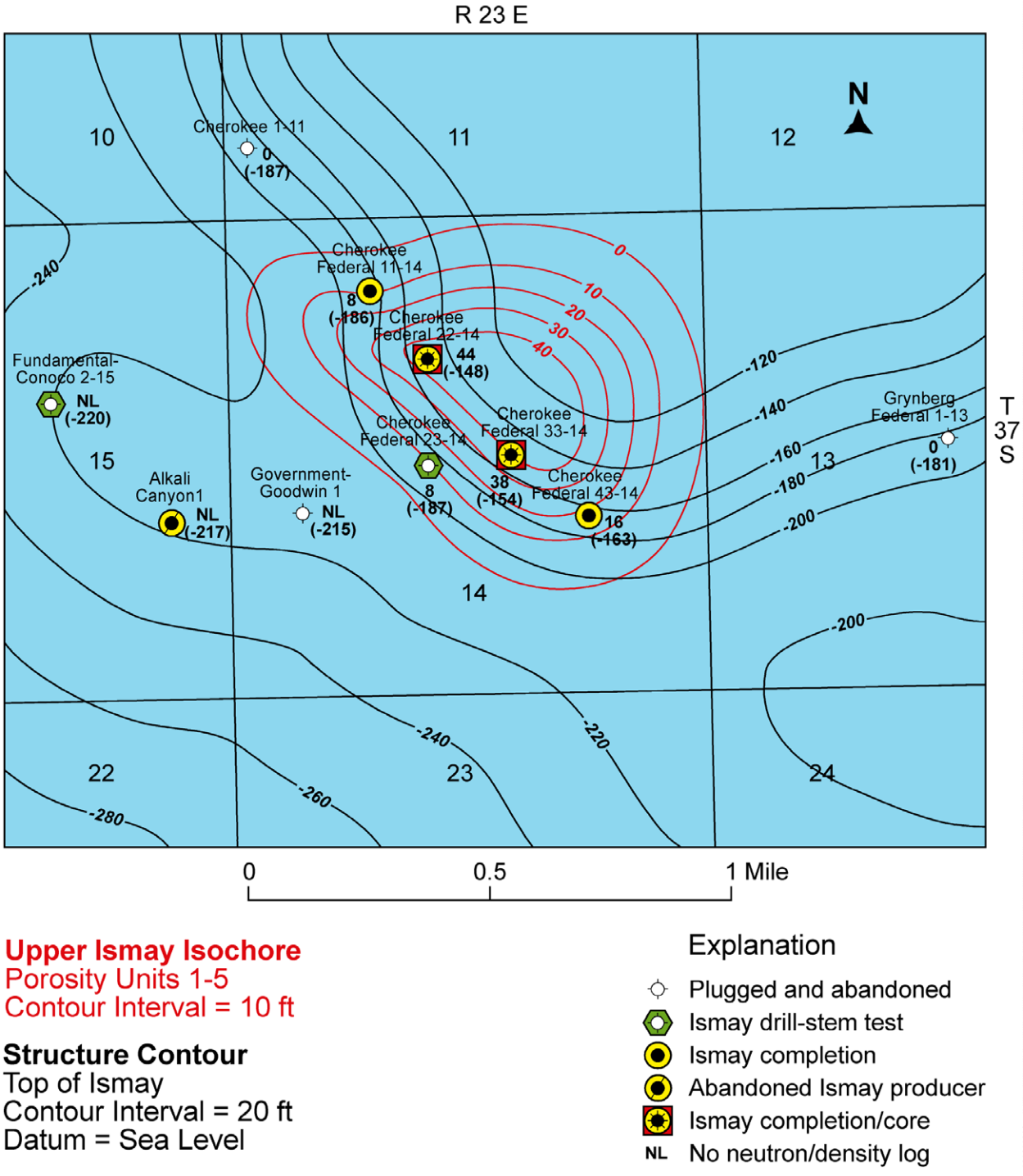
Depositionally, rock units are divided into seals or barriers (anhydrites and shales), mound (carbonate buildup), and off mound. Porosity units, reservoir or potential reservoir layers, are identified within the mound and off-mound intervals. The mound and some of the off-mound units are part of the clean carbonate - an interval where carbonate mudstone and shale are generally absent. The top and base of all these intervals (seals, mound, clean carbonate, as well as porosity units) are determined and coded as listed on table 1. The unlisted intervening units represent the baffles or non-reservoir rocks such as non-porous packestone or wackestone. The mound/mound cap intervals usually have porosity greater than 6 percent while the clean carbonate intervals are defined by lithology only (such as bafflestone or grainstone), although there may be occasional isolated porosity zones. The top and base of the mound/mound cap intervals are often equivalent to the clean top and base of the clean carbonate intervals. In addition, the top and base of the mound/mound cap intervals may be equivalent to the top and base of the thinner off-mound clean carbonate intervals.

In Cherokee field, six porosity units were identified, five of which occur in the upper Ismay mound and the other one in the lower part of clean carbonate. The lower porosity unit exhibits a “false porosity” on geophysical well logs that led the operator to perforate the interval and attempt a completion. However, examination of core, thin sections, and porosity and permeability data from core plug analysis shows the unit is incapable of fluid flow due to low permeability.

The correlation scheme will be used for: (1) predicting changes in reservoir and non-reservoir rocks across the field, (2) comparing field to non-field areas, (3) estimating the reservoir properties and identifying facies in wells which were not cored, and (4) determining potential units suitable for horizontal drilling projects. It can be applied to other fields in the Blanding sub-basin, both those with cores and without.

Reservoir Mapping

A structure contour map on the top of the upper Ismay zone and isochore porosity map were constructed for Cherokee field (figure 9). Isochore maps of the upper Ismay were generated for reservoir units containing 6 percent or more porosity based on the average of the neutron and density porosity values (figures 10 through 16). Isochore maps were also constructed for the entire upper Ismay zone, upper Ismay clean carbonate, Hovenweep shale, and upper Ismay anhydrite (figures 17 through 20). The latter two units represent effective seals. The maps display well names, Ismay completions, completion attempts, drill-stem tests, wells with core, and the subsea top and interval thickness for each well. These maps incorporate unit tops and thickness from all geophysical well logs in the area determined using the correlation scheme. They show carbonate buildup trends, define limits of field potential, and indicate possible horizontal drilling targets. Porosity units 1 through 5 were mapped together to produce a gross interval isochore which represents the actual producing reservoir (figure 9).



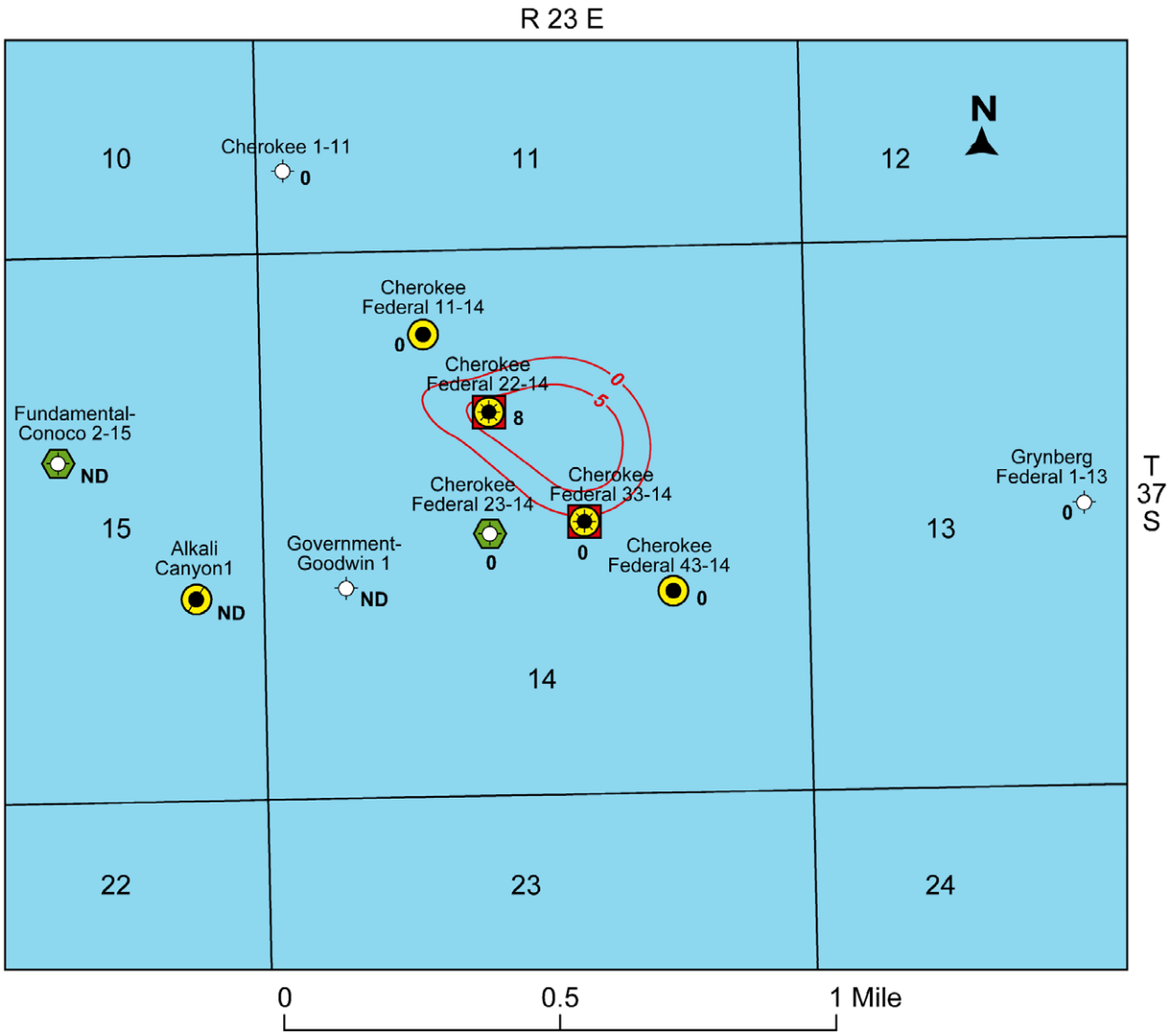
Upper Ismay Isochore
Porosity Units 1-5
Contour Interval = 10 ft

Structure Contour
Top of Ismay
Contour Interval = 20 ft
Datum = Sea Level

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core
- NL — No neutron/density log

Figure 9. Combined upper Ismay zone structure contour map and isochore map for porosity units 1 through 5, Cherokee field, San Juan County, Utah.



Isochore: Ismay Zone,
Porosity Unit 1
Contour Interval = 5 ft

Explanation

- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core
- ND — No neutron/density log

Figure 10. Isochore map for upper Ismay porosity unit 1, Cherokee field, San Juan County, Utah.

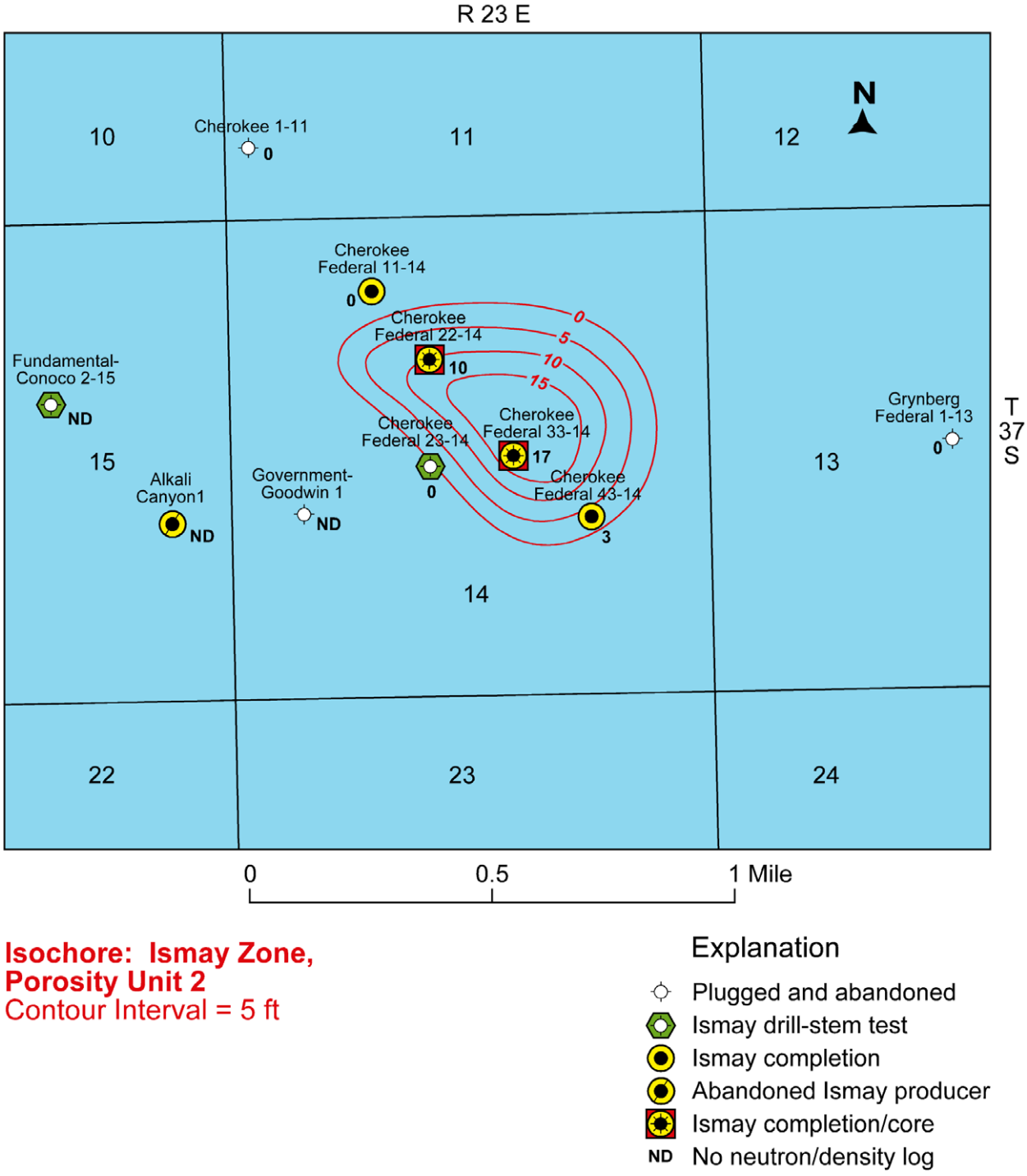


Figure 11. Isochore map for upper Ismay porosity unit 2, Cherokee field, San Juan County, Utah.

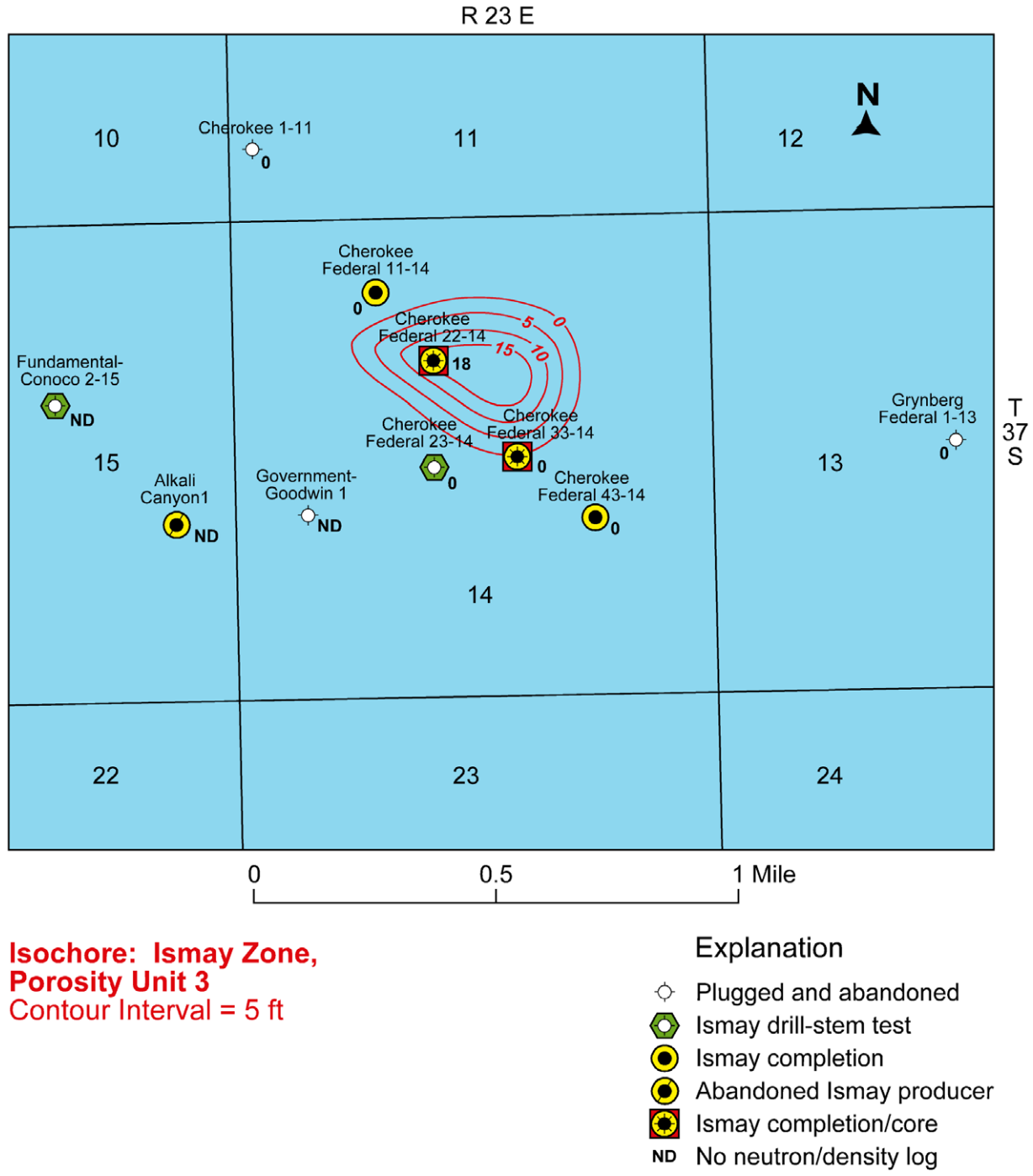


Figure 12. Isochore map for upper Ismay porosity unit 3, Cherokee field, San Juan County, Utah.

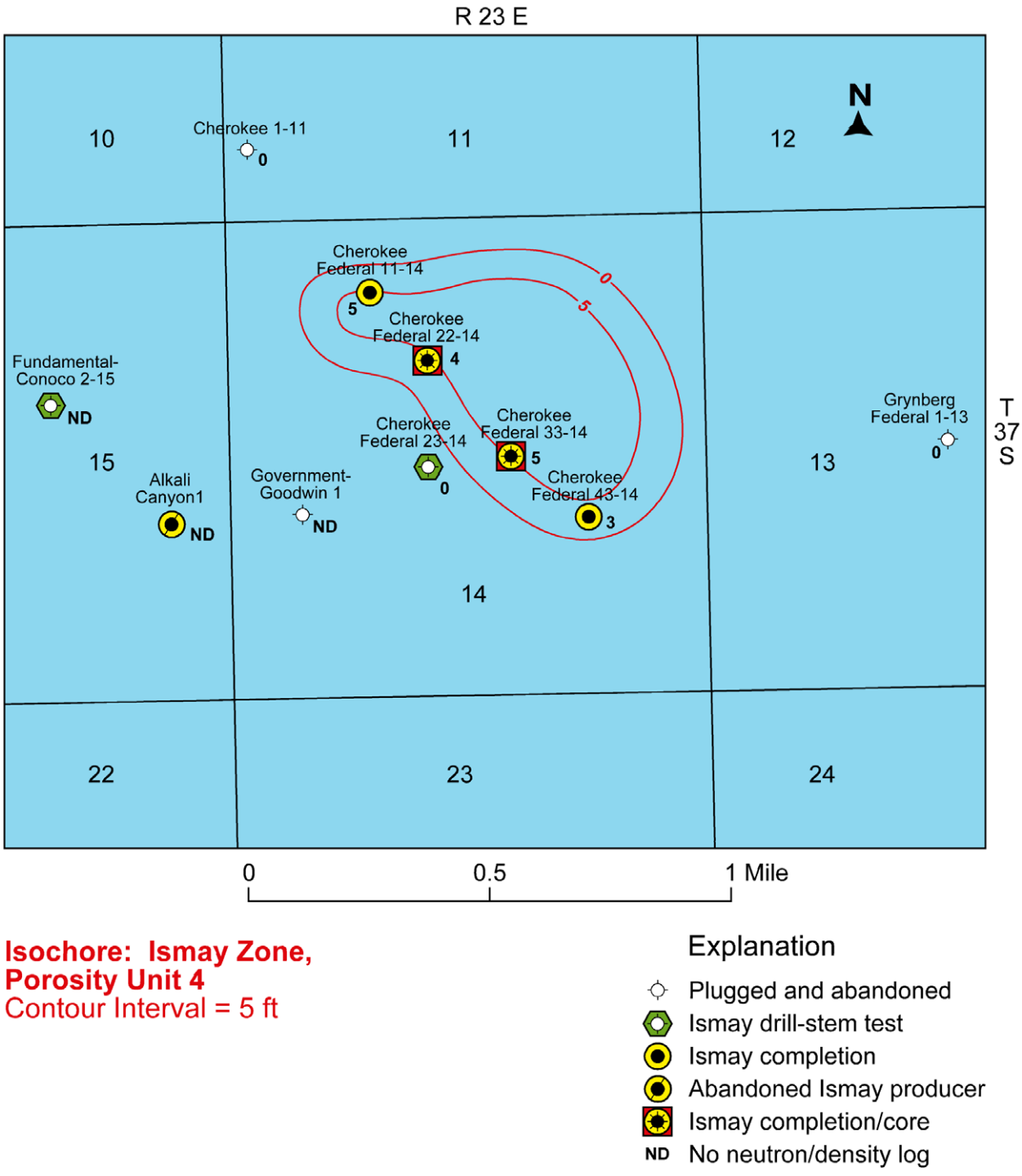


Figure 13. Isochore map for upper Ismay porosity unit 4, Cherokee field, San Juan County, Utah.

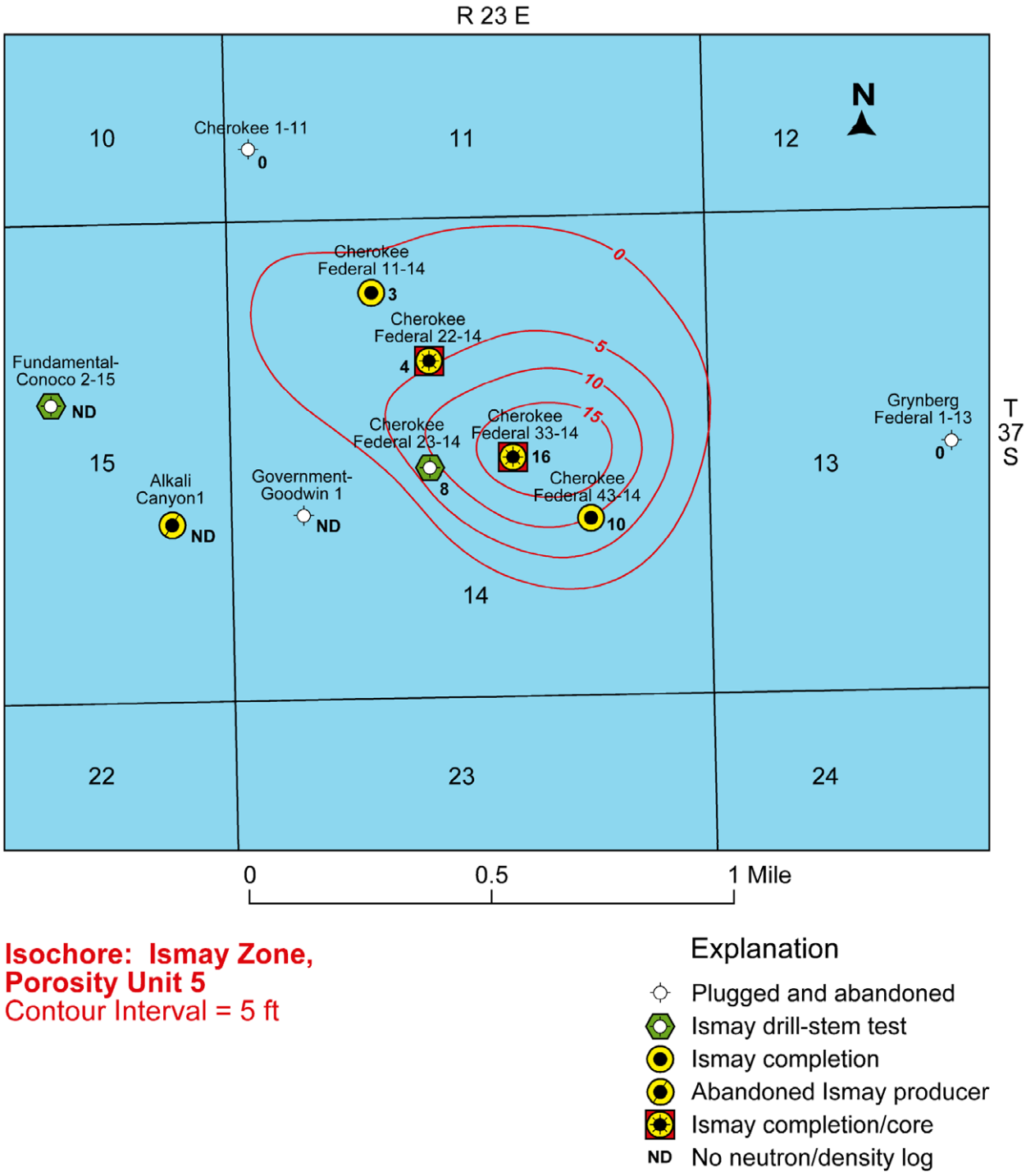


Figure 14. Isochore map for upper Ismay porosity unit 5, Cherokee field, San Juan County, Utah.

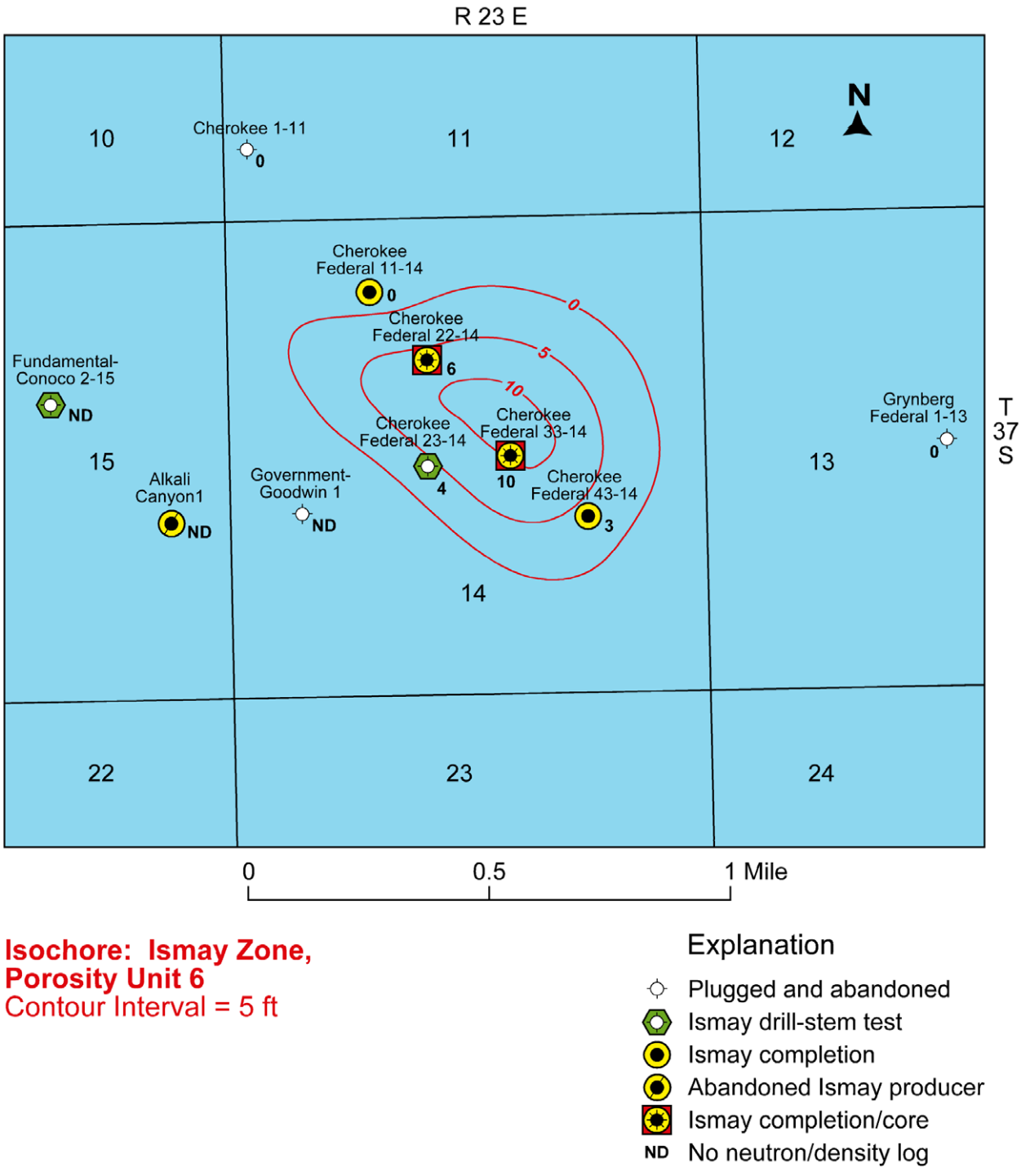


Figure 15. Isochore map for upper Ismay porosity unit 6, Cherokee field, San Juan County, Utah.

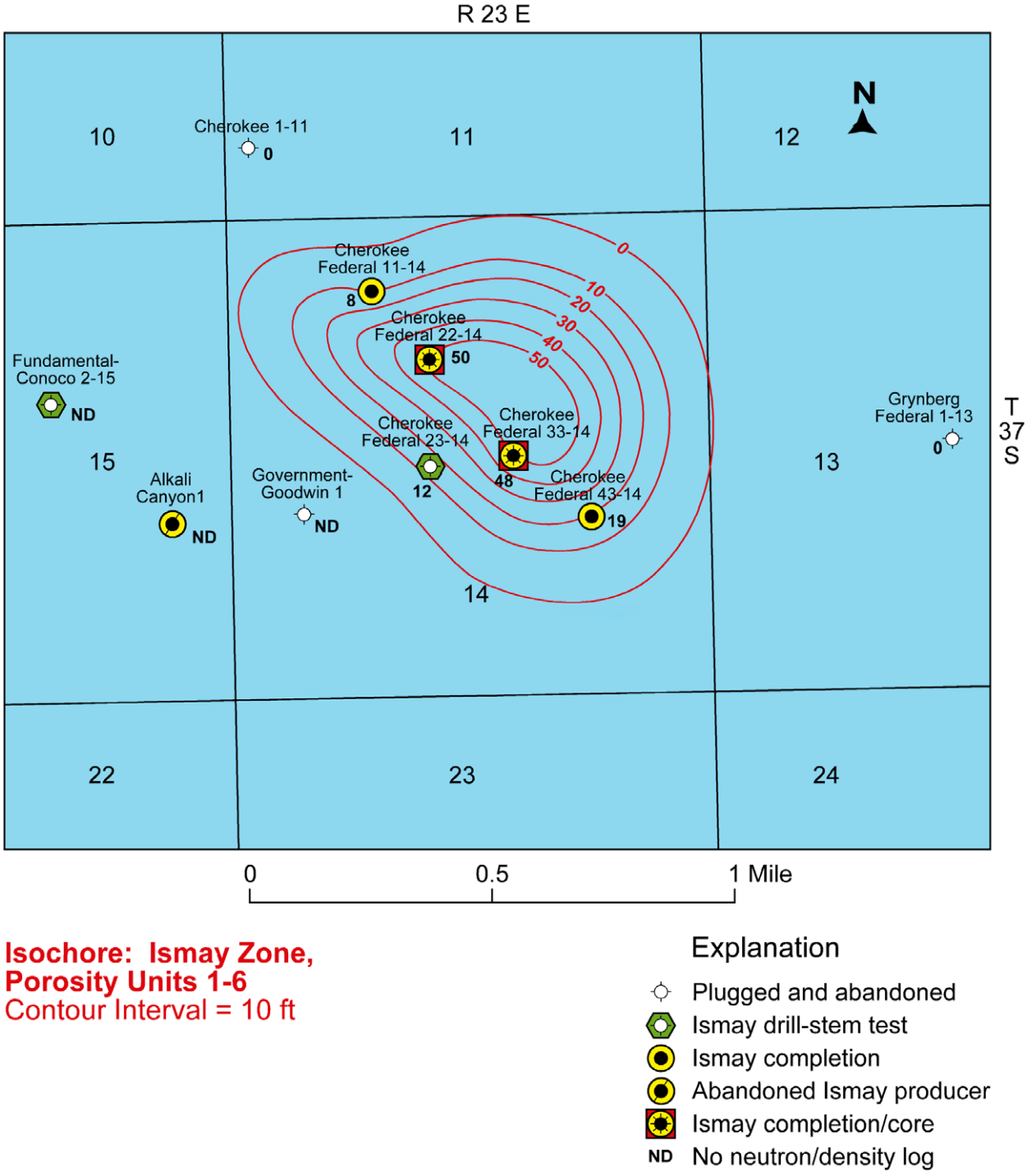


Figure 16. Isochore map for upper Ismay porosity units 1 through 6, Cherokee field, San Juan County, Utah.

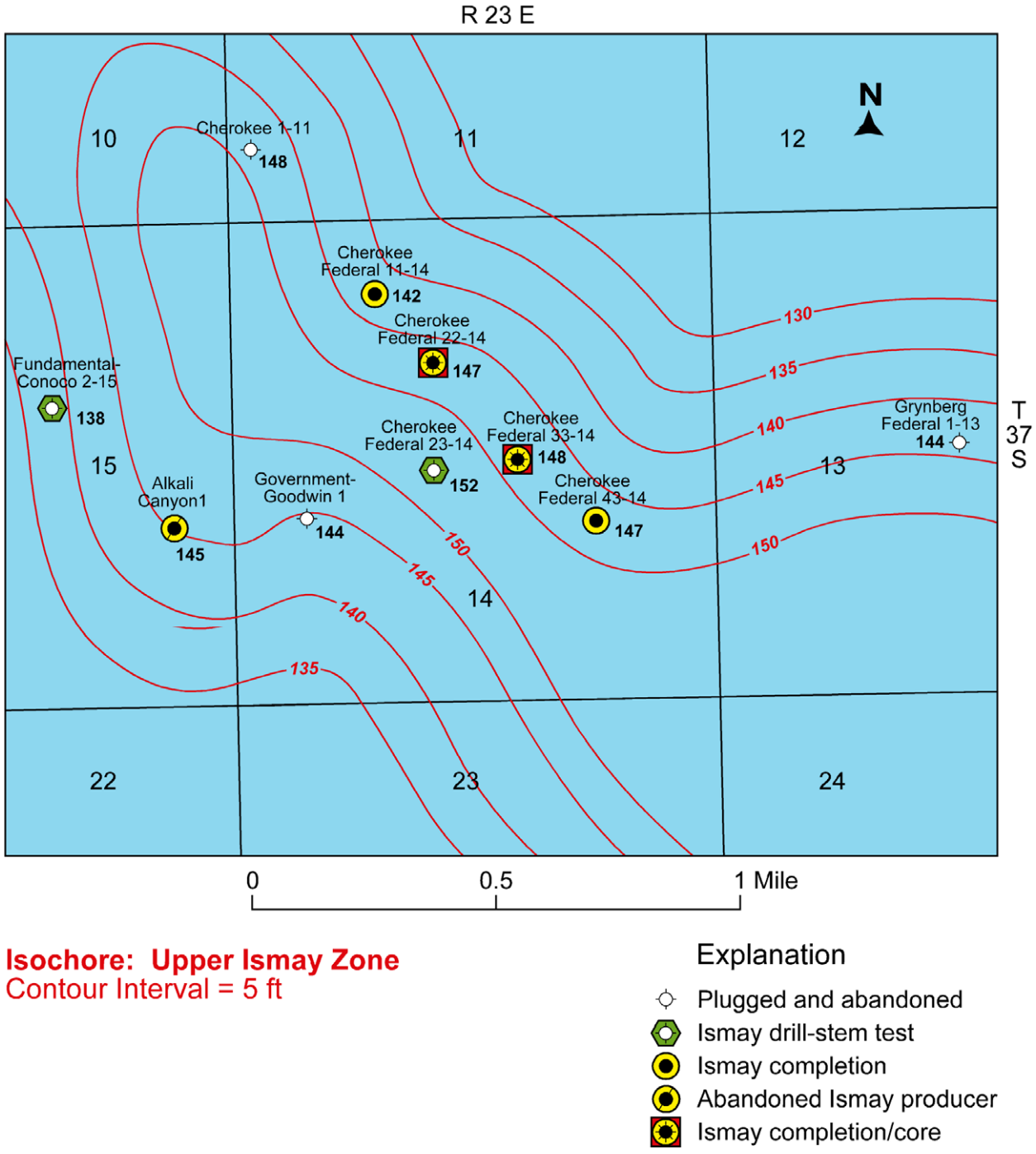


Figure 17. Isochore map for upper Ismay zone, Cherokee field, San Juan County, Utah.

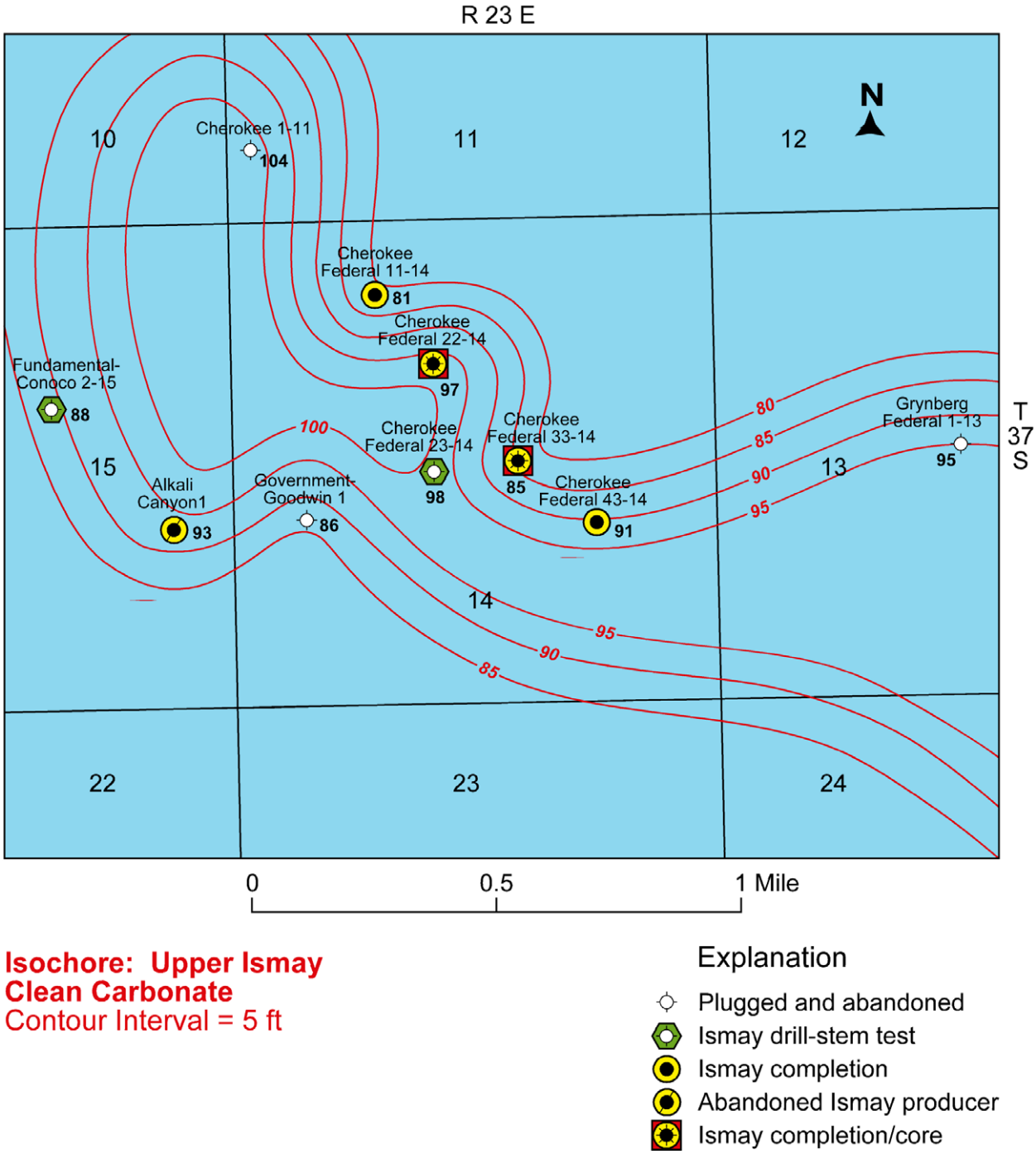


Figure 18. Isochore map for upper Ismay clean carbonate, Cherokee field, San Juan County, Utah.

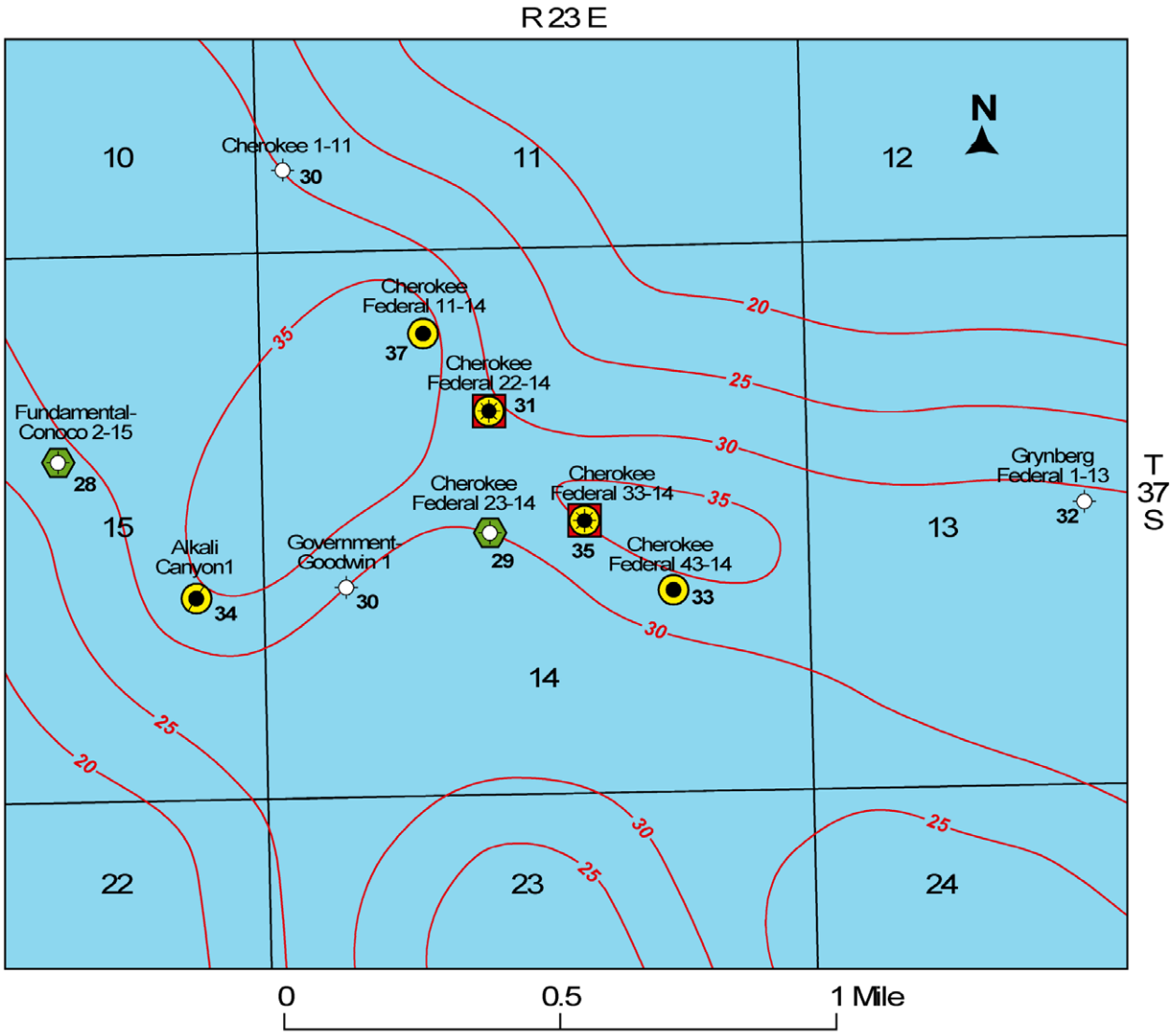
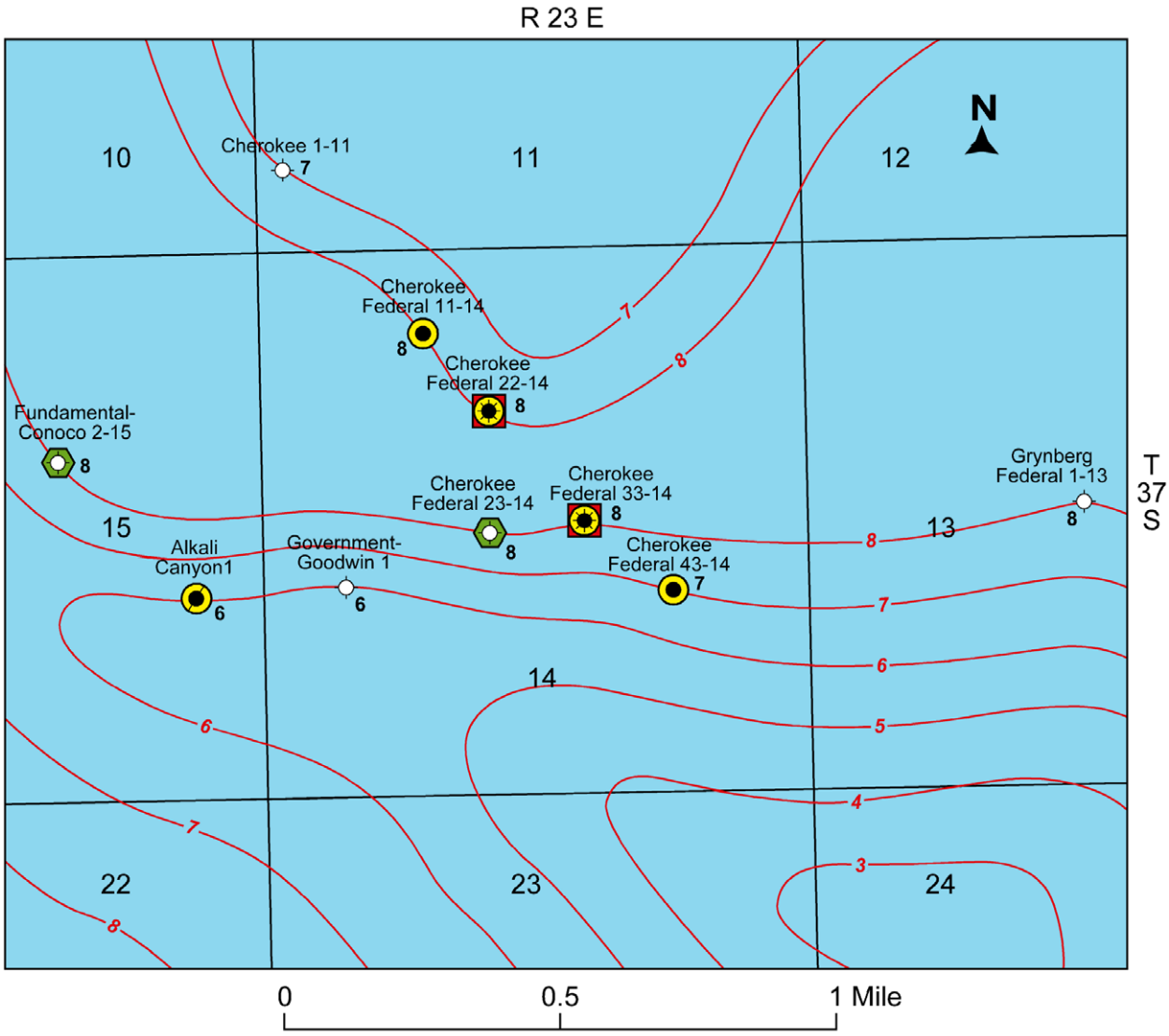


Figure 19. Isochore map for Hovenweep shale of the Ismay zone, Cherokee field, San Juan County, Utah.



Isochore: Upper Ismay Anhydrite
Contour Interval = 1 ft

Explanation
- Plugged and abandoned
- Ismay drill-stem test
- Ismay completion
- Abandoned Ismay producer
- Ismay completion/core

Figure 20. Isochore map for upper Ismay anhydrite, Cherokee field, San Juan County, Utah.

The structure contour, isochore, and other maps produced for Cherokee field, such as anhydrite and shale isochore maps, will be incorporated into the three-dimensional reservoir models developed later in the project.

TECHNOLOGY TRANSFER

The UGS is the Principal Investigator and prime contractor for five government-industry cooperative petroleum-research projects including two in the Paradox Basin. These projects are designed to improve recovery, development, and exploration of the nation's oil and gas resources through use of better, more efficient technologies. The projects involve detailed geologic and engineering characterization of several complex heterogeneous reservoirs. The two Class II Paradox Basin (this report cover the Class II Revisit project) and the Class I Bluebell field (Uinta Basin) projects include practical oil-field demonstrations of selected technologies. The fourth project involves geological characterization and reservoir simulation of the Ferron Sandstone on the west flank of the San Rafael uplift as a surface analogue of a fluvial-dominated, deltaic reservoir. The fifth project involves establishing a log-based correlation scheme for the Tertiary Green River Formation in the southwestern Uinta Basin to help identify new plays and improve the understanding of producing intervals. The DOE and multidisciplinary teams from petroleum companies, petroleum service companies, universities, private consultants, and state agencies are co-funding the five projects.

The UGS will release all products of the Paradox Basin project in a series of formal publications. These will include all the data as well as the results and interpretations. Syntheses and highlights will be submitted to refereed journals as appropriate, such as the *American Association of Petroleum Geologists (AAPG) Bulletin* and *Journal of Petroleum Technology*, and to trade publications such as the *Oil and Gas Journal*. This information will also be released through the UGS periodicals *Petroleum News, Survey Notes*, and on the project Internet web pages.

The technical team met with project Technical Advisory and Stake Holders Boards in Denver, Colorado, on June 1, 2001. Project activities and results were reviewed, including a display of representative core and thin section photomicrographs. The technical team obtained available reservoir data, and received initial feedback and advice concerning horizontal drilling in the case-study fields. The Technical Advisory Board is composed of field operators from the Paradox Basin. The Technical Advisory Board advises the technical team on the direction of study, reviews technical progress, recommends changes and additions to the study, and provides data. The Technical Advisory Board ensures direct communication of the study methods and results to the Paradox Basin operators. The Stake Holders Board is composed of groups that have a financial interest in the study area including representatives from the Utah and Colorado state governments (Utah School and Institutional Trust Lands Administration, Utah Division of Oil, Gas and Mining, and Colorado Oil and Gas Conservation Commission), Federal Government (U.S. Bureau of Land Management and U.S. Bureau of Indian Affairs), and the Ute Mountain Ute Indian Tribe. The members of the Technical Advisory and Stake Holders Boards receive all semi-annual technical reports and copies of all publications, core photographs, and other material resulting from the study.

Project materials, plans, and objectives were displayed at the UGS booth during the AAPG annual national convention, June 3-6, 2001, in Denver, Colorado. Four UGS scientists staffed the display booth at this event. Project displays will be included as part of the UGS booth at professional meetings throughout the duration of the project.

An abstract was submitted to the AAPG, on heterogeneous carbonate buildups in the Colorado portion of the Blanding sub-basin as targets for horizontal drilling techniques. If accepted, the paper will be presented during the 2002 AAPG annual national convention in Houston, Texas.

Utah Geological Survey *Petroleum News, Survey Notes,* and Internet Web Sites

The purpose of the UGS *Petroleum News* newsletter is to keep petroleum companies, researchers, and other parties involved in exploring and developing Utah's energy resources informed of the progress on various energy-related UGS projects. *Petroleum News* contains articles on: (1) DOE-funded and other UGS petroleum project activities, progress, and results; (2) current drilling activity in Utah including coalbed methane development; (3) new acquisitions of well cuttings, core, and crude oil at the UGS Core Research Center; and (4) new UGS petroleum publications. The purpose of *Survey Notes* is to provide nontechnical information on contemporary geologic topics, issues, events, and ongoing UGS projects to Utah's geologic community, educators, state and local officials and other decision makers, and the public. *Survey Notes* is published three times yearly and *Petroleum News* is published annually. Single copies are distributed free of charge and reproduction (with recognition of source) is encouraged. The UGS maintains a database that includes those companies or individuals (more than 300 as of October 2001) specifically interested in the Paradox Basin project or other DOE-sponsored projects.

The UGS and the CGS maintain web sites on the Internet, http://www.ugs.state.ut.us/ and http://www.dnr.state.co.us/geosurvey. The UGS site includes a page under the heading *Economic Geology Program*, which describes the UGS/DOE cooperative studies (Paradox Basin, Ferron Sandstone, Bluebell field, Green River Formation), contains the latest issue of *Petroleum News*, and has a link to the DOE web site. Each UGS/DOE cooperative study also has its own separate page on the UGS web site (figure 21). The Paradox Basin project page http://www.ugs.state.ut.us/paradox2.htm contains: (1) a project location map, (2) a description of the project, (3) a list of project participants and their postal addresses and phone numbers, (4) a reference list of all publications that are a direct result of the project, and (5) semi-annual technical progress reports. The CGS web site contains the same project information.

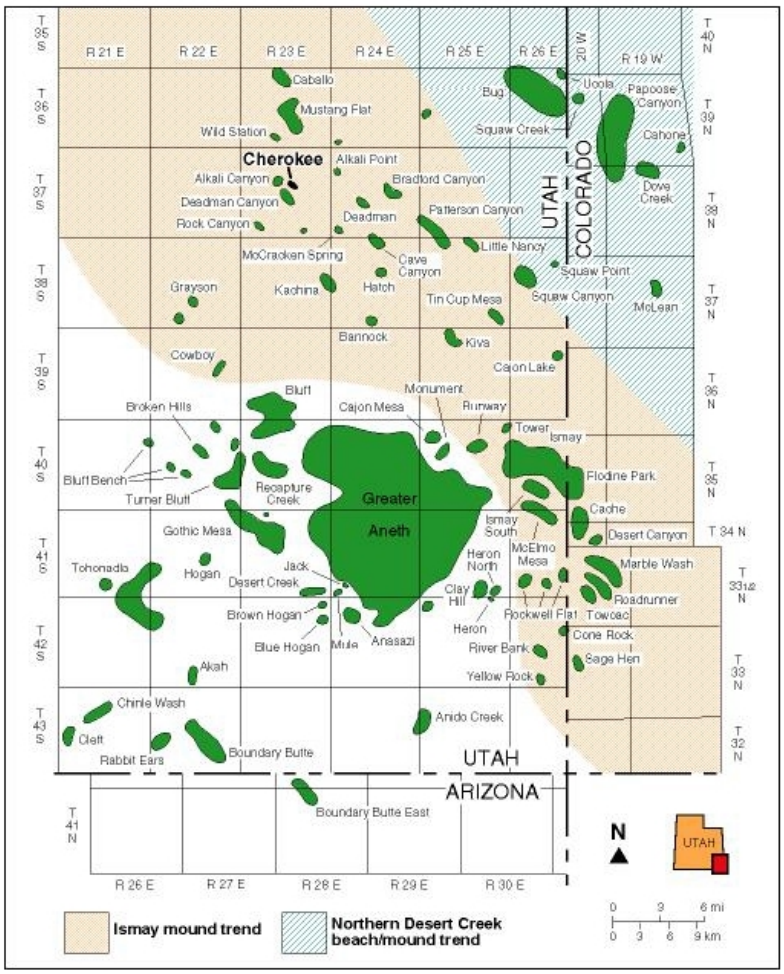
Paradox Basin II - DOE Class II Oil Revisit

Heterogeneous Shallow-shelf Carbonate Buildups in the Blanding Sub-basin of the Paradox Basin, Utah and Colorado: Targets for Increased Oil Production and Reserves Using Horizontal Drilling Techniques

The Paradox Basin, which extends from Utah into portions of Colorado and Arizona, contains more than 75 small oil fields, each capable of producing 2 to 10 million barrels of oil. But variations in the reservoirs of these fields prevent recovery of up to 75 percent of that resource, using conventional extraction methods.

This new 5-year study will evaluate methods to extract as much as another 50 million barrels of oil from existing wells in the basin. It will consist of a geologic and reservoir characterization study of the Ismay and Desert Creek zones of the 300-million-year-old Paradox Formation. The goal will be to determine if horizontal drilling techniques can increase well productivity from thin, untested intervals of reservoir rock. Cherokee field in San Juan County will be a target for a detailed case study.

The total cost of the project will be $1.03 million. Funding will come from the U.S. Department of Energy, the Utah Geological Survey, the Colorado Geological Survey, and private industry. The management and technical team, headed by UGS Principal Investigator Thomas C. Chidsey, Jr., will include Seeley Oil Company of Salt Lake City, the Colorado Geological Survey, and Eby Petrography & Consulting, Inc.



Utah Geological Survey
Project Home Page Internet Address

http://www.ugs.state.ut.us/paradox2/paradox2/htm

Reports

- Abstract
- Statement of Work

For more information on the Paradox Basin II Project, contact Tom Chidsey, (801) 537-3364, email: nrugs.tchidsey@state.ut.us.

Figure 21. The Paradox Basin project home page, http://www.ugs.state.ut.us/paradox2.htm, from the UGS Internet web site.

Presentation

The following technical presentation was made during the first six months of the second project year as part of the technology transfer activities.

> "Heterogeneous Carbonate Buildups in the Blanding Sub-Basin of the Paradox Basin, Utah and Colorado: Targets for Increased Oil Production Using Horizontal Drilling Techniques" by David E. Eby and Thomas C. Chidsey, Jr., American Association of Petroleum Geologists Annual Convention, Denver, Colorado, June 4-5, 2001. This presentation was made at a special poster session on Rocky Mountain reservoirs which included displays of representative core. Graphs, maps, diagenetic analysis, and horizontal drilling recommendations were also part of the presentation.

Project Publications

Chidsey, T.C., Jr., Eby, D.E., and Wray, L.L., 2001, Heterogeneous shallow-shelf carbonate buildups in the Paradox Basin, Utah and Colorado: targets for increased oil production and reserves using horizontal drilling techniques – semi-annual technical progress report for the period April 6 to September 5, 2000: U.S. Department of Energy, DOE/BC15128-1, 22 p.

Eby, D.E., and Chidsey, T.C., Jr., 2001, Heterogeneous shallow-shelf carbonate buildups in the Blanding sub-basin of the Paradox Basin, Utah and Colorado: targets for increased oil production using horizontal drilling techniques [abs.]: American Association of Petroleum Geologists Annual Convention, Official Program with Abstracts, v. 10, p. A55.

CONCLUSIONS

The Blanding sub-basin within the Pennsylvanian Paradox Basin developed on a shallow-marine shelf that locally contained algal-mound and other carbonate buildups. The two main producing zones of the Paradox Formation are the Ismay and the Desert Creek. The Ismay zone is dominantly limestone comprising equant buildups of phylloid-algal material. The Ismay is productive in fields of the southern Blanding sub-basin. The Desert Creek zone is dominantly dolomite comprising regional nearshore shoreline trends with highly aligned, linear facies tracts.

Establishment of the basic carbonate lithofacies belts and stratigraphic patterns within the Ismay and Desert Creek zones in the Blanding sub-basin are critical to the understanding of the fields being evaluated for the demonstration project. Geological characterization of facies on a regional scale is focusing on reservoir heterogeneity and lateral continuity. This task is utilizing representative core and modern geophysical well logs, 24 to date, to map regional lithofacies belts, determine major facies types, and grade various intervals for horizontal drilling suitability.

The depositional environments of the Ismay and Desert Creek zones, based on the core descriptions, show that the controlling factors were water depth, salinity, prevailing wave energy, and in the case of phylloid-algal growth, paleostructural position. Depositional facies include: basinal, open-marine shelf, open-marine organic buildups, calcarenites at the platform

edge (including carbonate islands), middle shelf or open platform interior, restricted inner shelf or platform interior evaporites, and shoreline and terrestrial siliciclastic deposits. Lithofacies from the middle shelf or open platform interior, principally the phylloid-algal mounds, form the dominant producing reservoirs in the Ismay and Desert Creek zones.

The log-based correlation scheme developed for the project ties the typical, vertical, core-derived sequence or cycle of depositional facies from the Cherokee case-study field in Utah, to its corresponding sequence of gamma-ray and neutron-density curves from geophysical well logs. The correlation scheme identifies major zone contacts, seals or barriers, baffles, producing or potential reservoirs, and depositional facies. Seals or barriers include anhydrite layers and shales. Baffles are those rock units that restrict fluid flow in some parts of the field, but may develop enough porosity and permeability in other parts through diagenetic processes or facies changes to provide a conduit for fluid flow or even oil storage.

In Cherokee field, six porosity units were identified in the upper Ismay zone. However, geophysical logs often exhibit a "false porosity" for some units that led to wasteful completion attempts. The cores reveal these zones to actually represent barriers or baffles to fluid flow. Log-defined units with real porosity represent potential targets for horizontal drilling and warrant further investigation. Structure contour and isochore maps from units in the upper Ismay zone for Cherokee field show carbonate buildup trends, define limits of field potential, and also indicate possible horizontal drilling targets.

ACKNOWLEDGMENTS

This ongoing research was performed under the direction of the Utah Geological Survey, Thomas C. Chidsey, Jr., Principal Investigator, as part of the Class II Oil Revisit Program of the U.S. Department of Energy, National Petroleum Technology Office, Tulsa, Oklahoma, contract number DE-FC26-00BC15128. The Contracting Officer's Representative is Gary D. Walker. Project participants include the Colorado Geological Survey, Seeley Oil Company, and Eby Petrography & Consulting, Inc.

Geophysical well logs were correlated by Craig D. Morgan, Utah Geological Survey. Core and petrophysical data were provided by Burlington Resources, Seeley Oil Company, and Wexpro Company. Jim Parker and Kevin McClure of the Utah Geological Survey produced figures. The report was reviewed by David Tabet and Mike Hylland of the Utah Geological Survey. Cheryl Gustin, Utah Geological Survey, formatted the manuscript for publication.

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